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FLUIDIC STATE-OF-THE-ART SYMPOSIUM

30 SEPTEMBER – [illegible] OCTOBER

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VOLUME VI

U.S. Army Materiel Command
Harry Diamond Laboratories
Washington, D.C.

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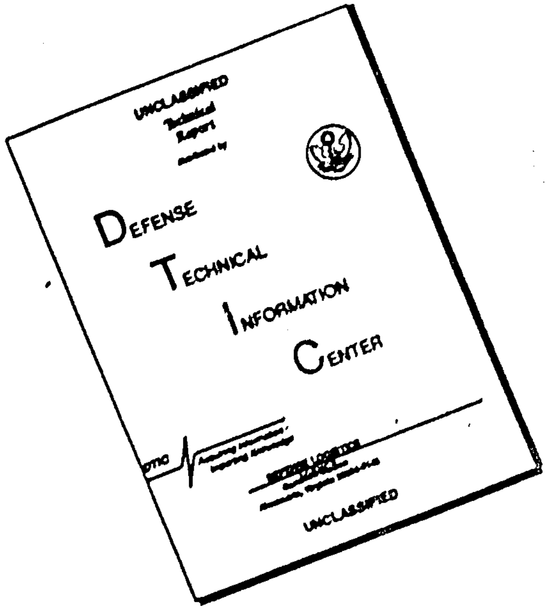

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FORWARD

This volume contains that part of the HDL Fluidics State-of-the-Art Symposium Proceedings that for one reason or another could not be published prior to the symposium.

I would like to take this opportunity to thank the discussors for their part in the symposium. All of us owe a debt to Sol Feinblum for suggesting an index, to the various authors for indexing their papers and in particular to Dawn Perry who compiled it. We are all also indebted to Ms Perry for spending many hours listening to, interpreting and typing the taped discussions, parts of which were down in the noise.

JOSEPH M. KIRSHNER

Per telecon (ltr on file)

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CONTENTS

WELCOMING ADDRESS OF CAPTAIN ROBERT WILLIAMSON II, COMMANDER, NAVAL SURFACE WEAPONS CENTER

I want to welcome you to the Naval Surface Weapons Center. It is perhaps appropriate before making any remarks about the purpose of the conference, to take about a minute and a half to tell you how it happens that this conference, which was scheduled to convene today at the Naval Ordnance Laboratory, White Oak, is in fact convening at the Naval Surface Weapons Center, White Oak.

About eleven days ago, the Chief of Naval Operations established the Naval Surface Weapons Center by merging all of the assets and resources of the Naval Ordnance Laboratory, White Oak and the Naval Weapons Laboratory, Dahlgren into a new RDT&E organization called the Naval Surface Weapons Center. The Naval Surface Weapons Center is designated as the principal Navy research, development, test and evaluation center for surface warfare weapon systems, ordnance technology, and strategic systems support; and I might add that the assets that I am talking about (depending upon how you count the people) represent somewhere between 5,600 and 6,000 Civil Service employees with associated military personnel.

Now, let us shift very quickly to the Fluidic State-of-the-Art Symposium and associated matters. At the Naval Surface Weapons Center we started specific application studies of what was then generally known as "pure fluids" technology in the early 1960s. Since that time we have followed the field of fluidics and fluerics closely and have experimented with fluidic components and less pure spin offs in various applications where their simplicity, reliability, and/or nuclear hardness

have offered system advantages. In these endeavors we have relied heavily on the expertise of Harry Diamond Laboratories' pioneers even to the extent of providing financial support in the case of several joint developments. We expect that our good working relationship will be further enhanced as the HDL work moves to its new location in Adelphi, Maryland. We at the Naval Surface Weapons Center see a continuing future for the application of fluidic principles and the related thought processes in mechanical design which they encourage for military and civil applications. We expect that our emphasis at this Center will continue to be on applications, while we rely on others, including many of you presenting papers at this symposium, to develop the basic understanding of components and system characteristics and manufacturing technology which is essential to continued progress.

I would like to digress from these remarks for one moment to introduce the Technical Director of the Naval Surface Weapons Center who is, I believe, known to many of you, Mr. Jim Colvard. With the consolidation of the Naval Weapons Laboratory and the Naval Ordnance Laboratory, Mr. Colvard, who has been at the Naval Weapons Laboratory, Dahlgren, for five years, most recently as Technical Director, has been appointed as the Technical Director of the Naval Surface Weapons Center.

Let me say again, it is a pleasure to welcome you to the Naval Surface Weapons Center.

Welcoming Address of Colonel David W. Einsel, Commanding Officer HDL

It is a real pleasure to welcome you to the Fluidics State-of-the-Art Symposium. First, I want to thank our fine hosts, the Naval Surface Weapons Center, Capt. Williamson the Commander and Jim Colvard the Technical Director. Their help has been consistent and continuous from the planning stages until the fine assistance this morning in the in-processing.

As we begin this symposium, it is appropriate to recognize and thank a goodly number of you in the audience and the even larger number that will be in and out of the symposium through the coming days. Only because of your diligent efforts has it been possible for our staff to put together the rather voluminous summary of your very excellent work. We express great thanks to all of you. It is a very real pleasure to welcome our many visitors from the university community, from industry, and, of course, from many of our sister laboratories.

Welcoming Address of B. M. Horton, Technical Director, HDL

I would like to join with Colonel Einsel in expressing my appreciation for the extremely gracious, effective, and efficient hosting that the Naval Surface Weapons Center is providing. If you ever want to move to a laboratory and you want to pick a neighbor I can't think of a better choice than the Naval Surface Weapons Center, (I guess it will still be NOL to me). For those of you who may not know, we are going to be back to back with them about a mile over the next ravine. We thank them very much for their gracious hospitality.

A few years back fluidics came in with a kind of a bang. It came in with a lot of optimism and it turned out that some of that optimism was excessive because although these devices as individual elements would perform very well, the connecting of them into complicated systems was pretty difficult. This optimism led to the early applications of fluidic devices in places where they still do a creditable job but it also led to disillusionment because of the complexities. The Navier Stokes equation is still a complicated beast.

Now when all this began we said that perhaps in the time of the Egyptians or certainly by Bernoulli's time we could have had a fluid amplifier because it has been obvious for a long time that with a little bit of control flow on the side of a stream the exchange of momentum between these two streams would cause the primary energy of the main stream to be diverted to one of two outlets or partitioned betwen them. But I am afraid that I have to admit that without the aid of the electronic calculator we never would have had the computational capability to

unscramble the Navier Stokes equation to come up with a really sophisticated analysis of these devices. The complexities of the fluid flow process with or without turbulence have beset these systems with difficulties for over a decade now and we are just now beginning to unscramble some of them. As a matter of fact, it is only about four or five years ago that we finally got to the point where we began to be able to do a meaningful analysis rather than only cutting hardware so that we have arrived at the point where we can analyse the geometric configuration and by doing enough cases (thank heaven for the electronic computer) we can essentially synthesise a device.

You who are in the audience are largely those who are responsible for this growth and our capability to handle this technology and we appreciate your help and participation. It has been a tough fight.

Some of us felt that it was about time that the current state be reviewed in order that those who were interested in the field would at least become aware of the tools that are available to them. We hope that our meeting today and this week will be a stimulant towards that state of understanding.

Each new technology has trouble in its time, our hope of course is that it will not be like a Boolean algebra which lay for the better part of a century before it was used or Walsh functions which just now about 50 years after their birth are coming into their own for certain kinds of analyses.

With that I think I will thank you for coming and only add that I will spend as much time as I can here, but because fluidics is just one of the things that we do at HDL and although it is one of my favorite things, I have to go for a part of this meeting to another set of activities.

Welcoming Address by Dr. R. B. Dillaway, Deputy for Laboratories, AMC

It is a real pleasure for me to be here this morning to help open this Fluidics Symposium. I am pleased to see the makeup of your program - particularly the fact that at least a third of it has to do with analysis of systems and applications for the fluidic technology. The three service deputies for labs have recently (under the aegis of the Joint Logistics Commanders) been looking at interdependence of technology among the services. Fluidics is one of the areas that we took a look at. We found that the technology was well coordinated between the services, NASA and everybody else in the fluidics community, but it was not moving out into applications as readily as we (those of us who were familiar with it and you practitioners) thought it ought to be. Yet very clearly though, there have been some interesting applications established. Several aircraft including the McDonald Douglas DC10 and Lockheed 1011 have fluidic systems in them. There is a fuel control on the F15. All these applications to the extent that they have been tried out, seem to be phenomenally successful. The thing that strikes the commercial people, of course, is the tremendous reliability and long mean time between failure of fluidics systems: this has great economic impact. However, the only program in a weapon system I know of that is going to production is one that the Navy has in a bomblet dispenser. We do have some applications of it in munitions manufacturing in government controlled plants but even there it seems to be a slow process to get expanded use implemented. I think that it may be that if we had put a larger fraction of our resources into fluidics compared with what we have put into advances in electronics it might have gone faster and we might be further along. I have done a lot of personal investigation into new systems to find out why fluidics weren't being used in

them where there is a logical advantage in use of fluidics systems. The answer that I usually get is, "Well, the technologists can show me components and equations for systems but I don't see anything on the shelf and I have a schedule to meet so that I just can't take a chance."

I have been personally pushing very hard in the Army (and I think that most of my lab directors have) to try to make sure that we have been getting across to our systems program managers and other systems responsible people the idea that we should consider a fluidic system whenever a new system is under development. This has had only limited success I am sorry to say. I think however that we have to push harder in this area and put more emphasis on it because the planners and the budgeteers and people who are in the policy making area are frankly beginning to wonder after 15 years of all this activity and apparent success in fluidics technology why isn't it being applied. Again, a major reason it isn't being applied is that the system people tend automatically to consider electronic systems because they are used to thinking that way. I think perhaps a lot of the problem is that they are not used to thinking fluidics and aren't familiar with it. Perhaps to some extent this is a result of too much talking to ourselves in this closely knit technical community and not really spending the time and effort required to make the potential users and other technologists understand truly what the state of the art is and how it can be used. This is extremely important if we are going to move forward in this technical area. We need then to get the word out.

One reason that I am very happy to see the amount of material gathered at this symposium is (as you might be interested to know) that Dr. Knausenberger

and I who are on the Guidance and Control Panel of AGARD have been tasked to put together an AGARDograph (which is an internal monograph for all the AGARD countries) on fluidics and our plan is to work with Mr. Kirsner to use parts of this symposium together with European papers. The AGARDograph will go to all the European NATO communities so it will help get the work out.

In a nut shell my message to you this morning is, "Get out and preach the gospel and get the word around." It is extremely important or I think this technology will begin to falter. It is something that has so many advantages it really behooves you to do this.

REGISTRATION LIST

NAME	ORGANIZATION
ADAMS, Gildford A.	Commander White Sands Missile Range ATTN: STEWS-TE-AG (Mr. Gildford A. Adams) White Sands Missile Range, NM 88002
ADAMS, Robert B.	Moore Products Company ATTN: Mr. Robert B. Adams Spring House, PA 19477
AHERN, C. J.	Bendix Research Laboratories Bendix Center ATTN: Mr. C. J. Ahern Southfield, MI 48076
ANDERSEN, Blaine N.	Brigham Young University 3014 N. Comanche ATTN: Blaine N. Andersen Provo, UT 84601
AYRE, Vernon	Commander US Army Missile Command ATTN: AMSMI-RGC (Mr. Vernon Ayre) Redstone Arsenal, AL 35809
BARRETT, John A.	Watervliet Arsenal Applied Math & Mech Div, B-124 ATTN: Mr. John A. Barrett Watervliet, NY 12189
BAUER, Peter	Bowles Fluidics Corporation 9247 Fraser Avenue ATTN: Mr. Peter Bauer Silver Spring, MD 20910
BAUMGARTH, Verlin	Rock Island Arsenal Rodman Lab ATTN: Mr. Verlin Baumgarth Rock Island, IL 61201
BEEKEN, Basil B.	Automatic Switch Company Hanover Road ATTN: Mr. Basil B. Beeken Florham Park, NJ 07932
BELL, Dr. A. C.	State University of New York at Buffalo Department of Mechanical Engineering ATTN: Dr. A. C. Bell Buffalo, NY 14214
BELLMAN, R. H.	Corning Glass Works Houghton Park, B-2 Corning, NY 14830
BELSTERLING, Charles A.	Franklin Institute Research Labs Ben Franklin Parkway ATTN: Mr. Charles A. Belsterling Philadelphia, PA 19103

NAME	ORGANIZATION
BENSO, W. E.	Autonetics, Division of Rockwell International 3370 Miraloma ATTN: Mr. W. A. Benso Anaheim, CA 92803
BOOTHE, W. A.	General Electric Company Bldg 506, Room 107 ATTN: Mr. W. A. Boothe Schenectady, NY 12345
BOUNDS, P.	Bendix Research Laboratories Bendix Center ATTN: Mr. P. Bounds Southfield, MI 48076
BOWLES, R. E.	Dr. R. E. Bowles, Engineering Consultant 2105 Sondra Court Silver Spring, MD 20904
BRODERSEN, Rolf K.	Martin Marietta Aerospace P.O. Box 5837, MP-326 ATTN: Mr. Rolf K. Brodersen Orlando, FL 32805
BROWN, Forbes T.	Lehigh University Dept of Mechanical Engineering and Mechanics ATTN: Dr. Forbes T. Brown Bethlehem, PA 18015
BYRD, Joe L.	Commander US Army Missile Command ATTN: AMSMI-RGC (Mr. Joe L. Byrd) Redstone Arsenal, AL 35809
CAMPAGNUOLO, Carl J.	Commander Harry Diamond Laboratories ATTN: Dr. Carl J. Campagnuolo Washington, DC 20438
CARTER, Vondell	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Vondell Carter) Washington, DC 20438
CHACONAS, Nicholas J.	Defense Documentation Center Cameron Station ATTN: Mr. Nicholas J. Chaconas Alexandria, VA 22314

NAME	ORGANIZATION
CHAIKIN, Art	Naval Sea Systems Command NAVSEA D331H ATTN: Mr. Art Chaikin Washington, DC 20362
CHARVONIA, David A.	OSD, ODDR&E (Engineering Technology) The Pentagon, Room 3D1089 ATTN: Dr. David A. Charvonia Washington, DC 20310
CHEN, Pah I.	Portland State University Applied Science & Engineering Dept ATTN: Professor Pah I. Chen Portland, OR 97201
CIRAS, Vitty P.	US Army Natick Labs ATTN: Mr. Vitty P. Ciras Natick, MA 01760
CLAYTON, B. J.	Army Missile Command Bldg. 5400 ATTN: AMSMI-RGP (B. J. Clayton) Redstone Arsenal, AL 35809
COLBORNE, W. G.	University of Windsor Dept of Mechanical Engineering ATTN: Dr. W. G. Colborne Windsor, Ontario, N9B 3P4 Canada
COLLINS, M.	4950 Test Wing (T2HM) Wright-Patterson AFB ATTN: (Mr. M. Collins) Dayton, OH 45433
COLLINS, T.	Bendix Corporation Aerospace Systems Division ATTN: Mr. T. Collins 400 South Beiger Street Mishawaka, IN 46544
COMPARIN, Robert A.	Newark College of Engineering 323 High Street ATTN: Robert A. Comparin Newark, NJ 07102
CORLEY , William	HQ, Pentagon Aviation Systems Division ATTN: DAMA-WSA (Ltc. William Corley) Room 3D369 Washington, DC 20310

NAME	ORGANIZATION
CORRADO, A. P.	EMX Engr Inc 354 Newark-Pompton Turnpike ATTN: A. P. Corrado Wayne, NJ 07470
COX, Lyndon S.	Commander Harry Diamond Laboratories ATTN: Mr. Lyndon S. Cox Washington, DC 20438
COXETER, George	Raymond Engineering Inc. 217 Smith Street ATTN: Mr. George Coxeter Middletown, CT 06457
CULBERTSON, Ralph L.	ARO Corporation One Aro Center ATTN: Mr. Ralph L. Culbertson Bryan, OH 43506
CZAJKOWSKI, Norman	Naval Ordance Laboratory ATTN: Mr. Norman Czajkowski, Code 412 Silver Spring, MD 20910
DAMMANN, Jeff	Commander Harry Diamond Laboratories ATTN: Dr. Jeff Dammann Washington, DC 20438
DAVIS, J. E. P.	Bennett Respiration Products, Inc. 1639-11th Street ATTN: Mr. J. E. P. Davis Santa Monica, CA 90406
DEADWYLER, Richard	Commander Harry Diamond Laboratories ATTN: Mr. Richard Deadwyler Washington, DC 20438
DELMEGE, Arthur H.	Sperry-Vickers P.O. Box 302 ATTN: Mr. Arthur H. Delmege Troy, MI 48084
DEPPERMAN, Warren B.	McDonnell-Douglas Astronautics Company P.O. Box 600 ATTN: Mr. Warren B. Depperman Titusville, FL 32780

NAME	ORGANIZATION
DeSABLA, Louis J.	Naval Ordnance Lab ATTN: Mr. Louis J. DeSabla, Code 412 Silver Spring, MD 20910
DILLAWAY, R. B.	Army Materiel Command 5001 Eisenhower Ave ATTN: R. B. Dillaway Alexandria, VA 22333
DOLAN, Paul R.	Fluidtech Corporation 945 W. Hyde Park Blvd. ATTN: Mr. Paul R. Dolan Inglewood, CA 90302
DOROFF, Stanley W.	Office of Naval Research ATTN: Mr. Stanley W. Doroff, Code 438 Arlington, VA 22217
DRAPEAU, D. L.	Chandler Evans Charter Oak Blvd. ATTN: Mr. D. L. Drapeau West Hartford, CT 06101
DRZEWIECKI, Tadeusz M.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Tadeusz M. Drzewiecki) Washington, DC 20438
DUNAWAY, J. C.	Commander US Army Missile Command ATTN: AMSMI-RGC (Mr. J. C. Dunaway) Redstone Arsenal, AL 35809
DURLAK, E. R.	Civil Engineering Laboratory ATTN: CBC (Mr. E. R. Durlak) Port Hueneme, CA 93043
EBERLE, Bill	Purdue University Aeronautics & Astronautics ATTN: (Bill Eberle) West Lafayette, IN 47907
EINSEL, D. W. Jr.	Commander Harry Diamond Laboratories ATTN: AMXDO-CO (Col. David W. Einsel, Jr.) Washington, DC 20438
EISENBERG, Norman A.	Enviro Control Inc. 1530 East Jefferson Street ATTN: Dr. Norman A. Eisenberg Rockville, MD 20852

NAME	ORGANIZATION
ENRIGHT, John	Johnson Controls, Inc. 507 E. Michigan Street ATTN: Mr. John Enright Milwaukee, WI 53201
EYTH, Jacob Jr.	Naval Air Development Center ATTN: Mr. Jacob Eyth, Jr. (Code 30424) Warminster, PA 18974
FASHBAUGH, Richard H.	Civil Engineering Lab Naval Construction Battalion Center ATTN: Dr. Richard H. Fashbaugh Port Hueneme, CA 93043
FECHNER, Erhard	Festo Corporation 10 Sintsink Drive East ATTN: Mr. Erhard Fechner Pt. Washington, NY 11050
FENNEMA, Paul J.	Bennett Respiration Products, Inc. 1639-11th Street ATTN: Mr. Paul J. Fennema Santa Monica, CA 90406
FINE, Jonathan	Commander Harry Diamond Laboratories ATTN: Mr. Jonathan Fine Washington, DC 20438
FINEBLUM, Solomon S.	Bell Laboratories Whippany Road ATTN: Mr. Solomon S. Fineblum Whippany, NJ 07981
FOSTER, Robert	Commander Harry Diamond Laboratories ATTN: Robert Foster Washington, DC 20438
FRANKE, Milton E.	Air Force Institute of Technology AFIT/ENM ATTN: Mr. Milton E. Franke Wright-Patterson Air Force Base Dayton, OH 45433
FRANZ, A.	Picatinny Arsenal CED, NDED, Bldg. 65 ATTN: Mr. A. Franz Dover, NJ 07801

NAME	ORGANIZATION
FREY, K.	5108 Averida Despacia Laguna Hill, CA 92653
FRIEDMAN, Sander B.	Miami University Dept of Engr Tech ATTN: Sander B. Friedman 142 Kreger Hall Oxford, OH 45056
FUNKE, Maurice	Commander Harry Diamond Laboratories ATTN: AMXDO-RCD (Mr. Maurice Funke) Washington, DC 20438
GALE, Manfred	Office Director of Army Research Pentagon, Room 3E365 ATTN: Manfred Gale Washington, DC 20310
GALLAGHER, T.	Electro-Motive Div. 9301 W. 55th Street ATTN: Thomas G. Gallagher LaGrange, IL 60525
GARNER, H. D.	NASA, Langley Center ATTN: H. D. Garner, MS-494 Hampton, VA 23665
GEREMIA, John O.	US Naval Academy Mechanical Engineering Department ATTN: John O. Geremia Annapolis, MD 21402
GESELL, William T.	Gesell Associates P.O. Box 4816 ATTN: Mr. William T. Gesell Fairview Park, OH 44126
GOTO, John M.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCD (Mr. John M. Goto) Washington, DC 20438
GOTTRON, Richard N.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCD (Mr. Richard N. Gottron) Washington, DC 20438

NAME	ORGANIZATION
GRAY, Everette E.	US Army Foreign Science & Technology Center 220 Seventh Street, NE ATTN: Cpt Everette E. Gray Charlottesville, VA 22901
GREENFIELD, William T. Jr.	Corning Glass Works Houghton Park, B-2 ATTN: Mr. William T. Greenfield, Jr. Corning, NY 14830
HARMAN, Charles	US Army Research Office P.O. Box CM, Duke Station ATTN: Dr. Charles Harman Durham, NC 27706
HAYNES, Roger R.	AiResearch Mf. Co. of Arizona 402 South 36th Street ATTN: Mr. Roger R. Haynes Phoenix, AZ 78712
HEALEY, Anthony	University of Texas 200 West 21st Street ATTN: Anthony Healey Austin, TX 78712
HEDEEN, James O.	Honeywell Inc. Government Aeronautical Products Div. 1625 Zarthan Avenue ATTN: James O. Hedeen St. Louis Park, MN 55416
HEHN, Anton H.	General American Research Division 7449 N. Natchez Avenue ATTN: Mr. Anton H. Hehn Niles, IL 60648
HERUTH, Kenneth	Ohio Medical Products 3030 Airco Drive ATTN: Mr. Kenneth Heruth Madison, WI 53701
HELLBAUM, R. F.	NASA, Langley Research Center ATTN: Mr. R. F. Hellbaum Hampton, VA 23665
HESTER, Leslie R.	Mississippi State University ATTN: Leslie R. Hester, Drawer A Mississippi State, MS 39762

NAME	ORGANIZATION
HONDA, Thomas S.	General Electric Company Specialty Fluidics Operation ATTN: Mr. Thomas S. Honda Building 37-511 Schenectady, NY 12345
HORTON, B. M.	Commander Harry Diamond Laboratories ATTN: AMXDO-TD (B. M. Horton) Washington, DC 20438
HOWARD, T. W.	Naval Air Systems Command 1421 Jefferson Davis Highway ATTN: T. W. Howard Bldg 2 Rm 960 Jefferson Plaza Arlington, VA 20360
HUGHES, Joseph M.	Commander US Army Materiel Command ATTN: Mr. Joseph M. Hughes 5001 Eisenhower Avenue Alexandria, VA 22333
HURLONG, G. W.	Bendix Research Laboratories Bendix Center ATTN: G. W. Hurlong Southfield, MI 48076
INGMAN, J. F.	Office Chief of Research, Development and Acquisition ATTN: DAMA-CSS (Ltc J. F. Ingman) Washington, DC 20310
ISEMAN, Joseph M.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Joseph M. Iseman) Washington, DC 20438
JACOBS, Paul L.	US Army Missile Command ATTN: AMSMI-RGC (Mr. Paul L. Jacobs) Redstone Arsenal, AL 35809
JANSEN, T.	93 Larkhill Street Apt. 410 St. Johns, Canada
JANSSON, David G.	Office of Naval Research 800 N. Quincy Street ATTN: Mr. David G. Jansson Arlington, VA 22216
JANU, George J.	Johnson Service Company 507 E. Michigan Street ATTN: Mr. George J. Janu Milwaukee, WI 53201

NAME	ORGANIZATION
JOYCE, James	Commander Harry Diamond Laboratories ATTN: Mr. James Joyce Washington, DC 20438
KAMPE, R. F.	Chandler Evans Charter Oak Blvd. ATTN: Mr. R. F. Kampe West Hartford, CT 06101
KELLER, Major Kenneth F.	Commander Harry Diamond Laboratories ATTN: AMXDO-AD (Major Kenneth F. Keller) Washington, DC 20438
KEYSER, David	Naval Ship Engineering Center Philadelphia Division ATTN: Mr. David Keyser, Code 6772 Philadelphia, PA 19112
KHATRI, Dr. Hiralel	Commander Harry Diamond Laboratories ATTN: AMXDO-RAC (Dr. Hiralel Khatri) Washington, DC 20438
KIRSHNER, Joseph M.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Joseph M. Kirshner) Washington, DC 20438
KLASS, Philip K.	Aviation Week & Space Technology Magazine 425 National Press Building ATTN: Mr. Philip J. Klass Washington, DC 20045
KNAUSENBERGER, George	Air Force Office of Scientific Research 1400 Wilson Blvd. ATTN: NE (Mr. George Knausenberger) Arlington, VA 22209
KRANZ, W.	in Messerchmitt-Bolkow-Blohm GmbH 8000 Muchen 80, Postrach 80 11 49 ATTN: Mr. W. Kranz Germany
KUMPTISCH, Robert C.	Specialty Fluidics Operations General Electric Company ATTN: Mr. Robert C. Kumptisch Building 37-511 Schenectady, NY 12345

NAME	ORGANIZATION
KWOK, Clyde C. K.	Sir George Williams University 1455 de Maisonneuve Blvd. West ATTN: Prof. Clyde C. K. Kwok Montreal 107, Quebec, Canada
LANHAM, Clifford E.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCD (Mr. Clifford E. Lanham) Washington, DC 20438
LAUBACHER, Benjamin	Defense Intelligence Agency ATTN: Mr. Benjamin Laubacher Rosslyn, VA 22209
LAUGHREY, Bill	Naval Air Systems Command ATTN: Mr. Bill Laughrey Washington, DC 20361
LEE, Henry	Commander Harry Diamond Laboratories ATTN: AMXDO-RCD (Mr. Henry Lee) Washington, DC 20438
LIN, Ho-ping	Stone & Webster Engineering Corp. 45 Englewood Avenue, #2 ATTN: Mr. Ho-ping Lin Boston, MA 02146
LYONS, Michael D.	Westinghouse Air Brake Company 1953 Mercer Road ATTN: Mr. Michael D. Lyons Lexington, KY 40505
MAJEWSKI, James	McDonnell-Douglas Astronautic Company P. O. Box 600 ATTN: Mr. James Majewski Titusville, FL 32780
MALCOLM, J. D.	MIT Dept of Mech Engr ATTN: Dr. J. D. Malcolm Cambridge, MA 02139
MANION, Francis M.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Francis M. Manion) Washington, DC 20438
MARKLAND, E.	Department of Mechanical Engineering University College ATTN: Prof. E. Markland Newport Road, Cardiff CF2 ITA Wales, UK
MARSHALL, Andrew J.	Sperry-Vickers 15 Mile & Crooks Road ATTN: Mr. Andrew J. Marshall Troy, MI 48084

NAME	ORGANIZATION
MARTIN, Charles A.	General Motors Institute 1700 W. Third Avenue ATTN: Mr. Charles A. Martin Flint, MI 48502
MATTSON, Richard W.	Preztel Light Electrical Division Eltre Corp 511 Hamilton Street ATTN: Richard W. Mattson Toledo, OH 43694
MAY, Clinton E.	General Electric Company 649 Pleasant Street ATTN: Clinton E. May Amherst, MA 01002
MAYER, L. F.	Aerospace Systems Division Bendix Corporation ATTN: Mr. L. F. Mayer 400 South Beiger Street Mishawaka, IN 46544
MEEHAN, J. R.	Rock Island Arsenal Rodman Laboratories ATTN: SARRI-LA-T (Mr. L. R. Meehan) Rock Island, IL 61201
MON, George	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Dr. George Mon) Washington, DC 20438
MOORE, Ernest F.	Air Force Flight Dynamics Lab Wright-Patterson Air Force Base ATTN: Mr. Ernest F. Moore Dayton, OH 45433
MORRIS, Joseph	Naval Ordnance Station ATTN: Mr. Joseph Morris, 50123B Indian Head, MD 20640
MOSES, Hal L.	Virginia Polytechnic Inst. Mech Engr Dept ATTN: Hal L. Moses Blacksburg, VA 24060
MURALI, B. N.	School of Mechanical & Aerospace Engineering Oklahoma State University ATTN: B. N. Murali Stillwater, OK 74074
McDONALD, Alan T.	School of Mechanical Engineering Purdue University ATTN: Alan T. McDonald West Lafayette, IN 47907

NAME	ORGANIZATION
McGIBONEY, Ralph L.	US Naval Air Development Center ATTN: AVTD (Mr. Ralph L. McGiboney) Warminster, PA 18974
NEAL, James	E. I. duPont de Nemours & Company Engineering Department ATTN: Mr. James P. Neal Louviers Bldg Wilmington, DE 19898
NERADKA, Vincent	Columbia Research Corporation P. O. Box 485 ATTN: Mr. Vincent Neradka Gaithersburg, MD 20760
NORTON, Stanley C., Jr.	Taylor Instrument Process Control Division Sybron Corporation ATTN: Mr. Stanley C. Norton, Jr. 95 Ames Street Rochester, NY 14601
NYSTROM, K. Sture	FFA, Fluid Technology Lab ATTN: Mr. K. Sture Nystrom S-161 11 Bromma 11 Sweden
OSWALD, Robert B., Jr.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Dr. Robert B. Oswald, Jr.) Washington, DC 20438
OTT, Harold N.	Naval Air Engineering Center Philadelphia Naval Base ATTN: Mr. Harold N. Ott Philadelphia, PA 19112
OWEN, Edward A.	Westinghouse Electric Corporation Research Laboratories ATTN: Mr. Edward A. Owen R&D Center, Bldg. 401 Pittsburgh, PA 15235
PAL, Dharam	Naval Civil Engineering Laboratory ATTN: Mr. Dharam Pal Port Hueneme, CA 93043
PARKER, G. A.	Department of Mechanical Engineering University of Surrey ATTN: Dr. G. A. Parker Guildford, Surrey, UK

NAME	ORGANIZATION
PATRICK, John P.	Hamilton Standard Division of United Aircraft Corp. ATTN: Mr. John P. Patrick Bradley Field Road Windsor Locks, CT 06096
PATTERSON, Dr. A. M.	Canadian Defense Research Staff 2450 Massachusetts Avenue, NW ATTN: Dr. A. M. Patterson Washington, DC 20008
PHILLIPPI, R. Michael	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. R. Michael Phillippi) Washington, DC 20438
POOR, Charles L.	Office of the Assistant Secretary Department of the Army ATTN: Mr. Charles L. Poor Washington, DC 20310
POTTER, R. C.	Westinghouse Nuclear P. O. Box 355 ATTN: Mr. R. C. Potter Pittsburgh, PA 15230
PRATT, John D.	Rodman Laboratories Rock Island Arsenal ATTN: SARRI-LA-T (Mr. John D. Pratt) Rock Island, IL 61201
RABSTEJNEK, Carl V.	IBM Corporation East Fishkill Facility ATTN: Mr. Carl V. Rabstejnek Dept 38A, Bldg. 300-97 Hopewell Junction, NY 12533
RAKOWSKY, Dr. Edward L.	EMX Engineering Incorporation 354 Newark-Pompton Tpke. ATTN: Dr. Edward L. Rakowsky Wayne, NJ 07470
RAMOS, Edward	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Edward Ramos) Washington, DC 20438
RANKIN, Gary	University of Windsor Dept of Mechanical Engineering ATTN: Gary Rankin Windsor, Ontario, N9B, Canada

NAME	ORGANIZATION
RANKIN, Tom M.	John Hopkins University Applied Physics Laboratory ATTN: Tom M. Rankin 8621 Georgia Avenue Silver Spring, MD 20910
READER, Kenneth R.	Naval Ship Research & Development Center ATTN: Mr. Kenneth R. Reader, Code 169 Bethesda, MD 20034
REID, Dr. Karl N.	School of Mechanical & Aerospace Engineering Oklahoma State University ATTN: Dr. Karl N. Reid Stillwater, OK 74074
RINGWALL, Carl G.	Specialty Fluidics Operation General Electric Company ATTN: Carl G. Ringwall Building 37-511 Schenectady, NY 12345
RIPKIN, Fred	Frankford Arsenal Bridge & Tacony Street ATTN: Mr. Fred Ripkin, PDM-P Philadelphia, PA 19137
ROE, George W.	McDonnell Douglas Astronautics Company P. O. Box 600 ATTN: Mr. George W. Roe Titusville, FL 32780
ROFFMAN, Gary L.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Gary L. Roffman) Washington, DC 20438
ROUECHE, Leon M.	Corning Glass Works Houghton Park, B-2 ATTN: Mr. Leon M. Roueche Corning, NY 14830
ROWELL, Eugene E. III	Mr. Eugene E. Rowell, III 162-D Malibu Place Newportnews, VA 23602
ROYLE, Professor J. K.	Department of Mechanical Engineering University of Sheffield ATTN: Professor J. K. Royle Mappin Street Sheffield S1 3JD, UK

NAME	ORGANIZATION
RUMPF, Richard L.	Applied Physics Laboratory John Hopkins University ATTN: Richard L. Rumpf 8621 Georgia Avenue Silver Spring, MD 20910
RUSSELL, G. Kenneth	Wilkerson Corporation 1201 W. Mansfield ATTN: Mr. G. Kenneth Russell Englewood, CO 80110
SAMPAR, David G.	Picatinny Arsenal ATTN: SARPA-ND-C-C (Mr. David G. Sampar) Dover, NJ 07801
SARPKAYA, T.	Naval Postgraduate School Department of Mechanical Engineering ATTN: Prof. T. Sarpkaya, Code 59SL Monterey, CA 93940
SAUERWALT, Arthur, Jr.	Naval Ship Engineering Center Philadelphia Division Code 6772 ATTN: Mr. Arthur Sauerwalt, Jr. Philadelphia, PA 19112
SCESNEY, David E.	Corning Glass Works Houghton Park, B-2 ATTN: Mr. David E. Scesney Corning, NY 14830
SCHAEDEL, H. M.	Fachhochschule Koln 51 Aachen Malmedyer Str. 76 ATTN: Dr. H. M. Schaedel West Germany
SCHAFFER, David J.	AiResearch Manufacturing Company 402 S. 36th Street ATTN: Mr. David J. Schaffer P. O. Box 5217 Phoenix, AZ 85010
SCHEIDLER, Fred E.	Hamilton Standard Division Mail Stop 12-3-3 ATTN: Mr. Fred E. Scheidler Windsor Locks, CT 06906

NAME	ORGANIZATION
SCHMIDLIN, A. E.	Picatinny Arsenal CED, NDED, Bldg. 65 ATTN: A. E. Schmidlin Dover, NJ 07801
SCHMIDT, Edward T.	Naval Air Development Center ATTN: AVTD (Mr. Edward T. Schmidt) Warminster, PA 18974
SCHOENAU, Greg J.	University of Saskatchewan ATTN: Greg J. Schoenau Saskatoon, SASK S7NOWO, Canada
SCHURMAN, Walter, R.	Monsanto Research Corp. ration Mound Road ATTN: Mr. Walter R. Schurman P. O. Box 32 Miamisburg, OH 45342
SELENO, A. A.	Bendix Research Laboratories Bendix Center ATTN: Mr. A. A. Seleno Southfield, MI 48076
SEWELL, Clint	Naval Ordnance Lab Division 412 ATTN: Mr. Clint Sewell Silver Spring, MD 20910
SHARKI, Martin J.	Dresser SWACO P. O. Box 1407 DC2 ATTN: Mr. Martin J. Sharki Houston, TX 77001
SHEARER, J. L.	Pennsylvania State University Dept of Mechanical Engineering ATTN: J. L. Shearer University Park, PA 16802
SHEN, Dr. C. N.	Benet Weapons Lab Watervliet Arsenal ATTN: Dr. C. N. Shen Watervliet, NY 12189
SHIMRONY, Yoram	Tel-Aviv University Ramat-Aviv, Tel-Aviv 69978 ATTN: Yoram Shimrony Israel

NAME	ORGANIZATION
SNOWBALL, Harry M.	Air Force Flight Dynamics Lab/FGL Wright-Patterson Air Force Base ATTN: Mr. Harry M. Snowball Dayton, OH 45433
SOLOMON, Merrill	Merrill & Company Suite 1000 ATTN: Mr. Merrill Solomon 1019 Nineteenth Street, NW Washington, DC 20036
SOMERS, James F.	Hamilton Standard Mail Stop 1a-3-5 ATTN: Mr. James F. Somers Windsor Locks, CT 06096
SOWERS, Edwin U., III	Mr. Edwin U. Sowers, III P. O. Box 216 Quantin, PA 17083
SPYROPOULOS, Chris	Commander Harry Diamond Laboratories ATTN: AMXDO-RDD (Mr. Chris Spyropoulos) Washington, DC 20438
SRIDHAR, K.	University of Windsor Dept of Mechanical Engineering ATTN: K. Sridhar Windsor, Ontario, N9B 3P4, Canada
STACILAUSKAS, Ronald	Lear Siegler, Inc. 4141 Easter, SE ATTN: Mr. Ronald Stacilauskas Grand Rapids, MI 49508
STERN, H.	General Electric Company Specialty Fluidics Operation ATTN: Mr. H. Stern Building 37-511 Schenectady, NY 12345
STOY, Dr. Robert L.	Techicon Instruments Corporation 511 Bendict Avenue ATTN: Dr. Robert L. Stoy Tarrytown, NY 10591
STRAITZ, John F.	National Airoil Burner 1284 E. Sedgley Avenue ATTN: Mr. John F. Straitz Philadalphia, PA 19134

NAME	ORGANIZATION
STRAUB, Henrik A.	Boeing Company P. O. Box 3707 ATTN: Mr. Henrik A. Straub, MS77-39 Seattle, WA 98124
STRYKER, David P.	Lear Siegler, Inc. 4141 Eastern, SE ATTN: Mr. David P. Stryker Grand Rapids, MI 49508
SUTTON, Trevor G.	AiResearch Manufacturing Company P. O. Box 5217 ATTN: Mr. Trevor G. Sutton Phoenix, AR 85010
TAFT, Dr. C. K.	University of New Hampshire ATTN: Dr. C. K. Taft Durham, NH 03824
TANNEY, J. W.	Low Speed Aero Laboratory National Research Council ATTN: Mr. J. W. Tanney Monteral Road Ottawa, Canada K1A 0R6
TAPLIN, L. B.	Bendix Research Laboratories Bendix Center ATTN: Mr. L. B. Taplin Southfield, MI 48076
TAYLOR, Donald L.	Lockheed California Company Dept. 74-75, Bldg. 229, Plant 2 ATTN: Mr. Donald L. Taylor Burbank, CA 91503
TAYLOR, Ernest A.	Monsanto Textiles Company P. O. Box 2204 ATTN: Mr. Ernest A. Taylor Decatur, AL 35601
TAYLOR, Wesley L.	Powers Regulator Company 3400 W. Oakton Street ATTN: Mr. Wesley L. Taylor Skokie, IL 60076
TENNEY, Stephen M.	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Stephen M. Tenney) Washington, DC 20438

NAME	ORGANIZATION
THOMPSON, Dr. R. V.	Marine Industries Centre 24 Claremont Place ATTN: Dr. R. V. Thompson Newcastle upon Tyne NE2 4AA, England
TILLMAN, H.	Messerschmitt-Bolkow-Blohm GmbH ATTN: Mr. H. Tillman 8000 Munchen 80, Postfach 80 11 49 Germany
TIPPETTS, Dr. J. R.	Sheffield University Dept of Chem Engrg & Fuel Tech ATTN: Dr. J. R. Tippetts Mappin Street, Sheffield S1 3JD, UK
TODA, Kenji	Commander Harry Diamond Laboratories ATTN: AMXDO-RCA (Mr. Kenji Toda) Washington, DC 20438
TORAIN, Alfonzo M.	Defense Documentation Center Cameron Station ATTN: Mr. Alfonzo M. Torain Alexandria, VA 22134
TOWNSEND, Philip E.	Rock Island Arsenal Rodman Lab ATTN: Mr. Philip E. Townsend Rock Island, IL 61201
TUREK, Robert F.	Lintec, Inc. 7 Dalamar Street ATTN: Mr. Robert F. Turek Gaithersburg, MD 20760
TUZSON, J.	Borg-Warner, Research Center Wolf & Algonquin Roads ATTN: Mr. John Tuzson Des Plaines, IL 60018
TRIVELPIECE, Dr. Alvin W.	Atomic Energy Commission Div of Controlled Thermonuclear Research ATTN: Dr. Alvin W. Trivelpiece Washington, DC 20545
TRYBUL, Dr. T. S.	Army Advance Materiel Command Agency 5001 Eisenhower Avenue ATTN: Dr. T. S. Trybul Alexandria, VA 22333
VanPROOYEN, Capt. Jan	Defense Nuclear Agency ATTN: RAEV (Capt. Jan Van Prooyen) Washington, DC 20305

NAME	ORGANIZATION
WADA, Professor Tsutomu	Okayama University ATTN: Professor Tsutomu Wada Okayama, Japan
WAGNER, Paul M.	Air Force Flight Dynamics Lab Wright-Patterson Air Force Base ATTN: Mr. Paul M. Wagner
WAGNER, Samuel C., IV	Commander Harry Diamond Laboratories ATTN: AMXDO-RC (Mr. Samuel C. Wagner, IV) Washington, DC 20438
WARE, Robert N.	Army Mobility Equipment R&D Center ATTN: STSFB-EP (Mr. Robert N. Ware) Ft. Belvoir, VA 22060
WARREN, Raymond	Mr. Raymond Warren 7925 Falstaff Road McLean, VA
WEBBER, Dr. G. E.	Honeywell Inc. 2600 Ridgway Parkway ATTN: Dr. G. E. Webber Minneapolis, MN 55413
WELK, Horace B.	Naval Air Development Center ATTN: AVTD (Horace B. Welk, 30424) Warminster, PA 18974
WEST, Wilber E., Jr.	Frankford Arsenal Bridge & Tacony Streets ATTN: Wilber E. West, Jr. Philadelphia, PA 19137
WESTERMAN, Dr. W. J.	McDonnell-Douglas Astronautics Company P. O. Box 600 ATTN: Dr. W. J. Westerman Titusville, FL 32780
WILLIAMS, Robert M.	Naval Ship R&D Center Aviation & Surface Effects Dept ATTN: Mr. Robert M. Williams, Code 1605 Bethesda, MD 20034
WILLIAMSON, Capt. Robert, II	Commander Naval Ordnance Lab ATTN: Capt. Robert Williams, II White Oaks, MD 20910

NAME	ORGANIZATION
WILSON, William G.	Hercules Inc. Alleghany Ballistics Lab ATTN: Mr. William G. Wilson Cumberland, MD 21502
WOJCIKOWSKI, R. J.	Dana Corporation Technical Center ATTN: Mr. R. J. Wojcikowski 8000 Yankee Road Ottawa Lake, MI 49267
WOODS, Dr. Robert L.	University of Texas at Arlington Mechanical Engineering Department ATTN: Dr. Robert L. Woods Arlington, TX 76010
WOODWARD, Dr. Kenneth F.	US Army Medical Bioengineering R&D Lab Fort Detrick ATTN: Dr. Kenneth F. Woodward Frederick, MD 21701
WORMLEY, Dr. David N.	Massachusetts Institute of Technology Room 3-146 ATTN: Dr. David N. Wormley Cambridge, MA 02139
WRIGHT, Lorraine D.	Rock Island Arsenal Rodman Laboratories ATTN: SARRI-LA-AC (Ms. Lorraine D. Wright) Artillery & Armored Weapon Systems Directorate Rock Island, IL 61201
WRIGHT, Robert E.	McDonnell-Douglas Astronautics Company P. O. Box 600 ATTN: Mr. Robert E. Wright Titusville, FL 32780
YOUNG, Robert W.	GE-RESD 3198 Chestnut Street ATTN: Mr. Robert W. Young Philadelphia, PA 19101
ZALESKY, Capt. Paul	Air Force School of Aerospace Medicine ATTN: VNT (Capt. Paul Zalesky) Brooks Air Force Base San Antonio, TX 78218
ZOYA, Walter J.	Sperry-Vickers P. O. Box 302 ATTN: Mr. Walter J. Zoya Troy, MI 48084

BIOGRAPHICAL DATA ON AUTHORS

Robert B. Adams

Mr. R. B. Adams is Director of Research at Moore Products Co., manufacturer of industrial instruments, controls and pneumatic comparator gages

Mr. Adams received his Bachelor and Master of Science degrees in mechanical engineering from MIT and has beem employed in development and research by the Moore Products Co. for twenty-one years. He is credited with fourteen patents and is co-inventor of five additional patents. He is also an Adjunct Associate Professor in mechanical engineering at Drexel University Evening College.

W. J. Anderson

Education:

Phoenix College - various Engineering courses

Work History:

1947 - 1952	-	Broadcast Transmitter Engineer
1952 - Date	-	Time Study Analyst and Method Engineer (Presently responsible for photo-fabrication facility and photo-fabrication processes)

Basil B. Beeken

Mr. Beeken is presently Director of Research for the ASCO Air Controls Department where he is responsible for advancing the state of the art in Fluidics.

Prior to his association with ASCO, he was Manager of New Product Research at Pitney-Bowes.

Mr. Beeken joined Pitney-Bowes in 1962 as a Senior Physicist, and has been engaged in wall attachment fluid amplifier and sensor research, document propulsion and control, ultra high frequency sonic generation and detection for use as an input sensor in fluidic transducers for interfacing with other technologies. He also has contributed significantly to the development of fluidic to mechanical devices. His research and analysis of the forces available for fluidic document handling have provided the basis for Pitney-Bowes advancements in this field. He has applied for eighteen patents relating to fluidics, sixteen of which he now holds.

Basil B. Beeken (cont.)

Formerly, Mr. Beeken was Research Assistant and instructor at Yale University where he was engaged in plasma research, an area in which he has published. Concurrently with this work, he was chairman of the Science Department of the University of New Haven as well as an Associate Professor in Physics.

He is a member of the American Physical Society, Fluid Power Society and is the review chairman for the fluidics section of the Instrument Society of America.

His publications in the field of fluidics include:

"A Theoretical and Experimental Study of a Coanda Curved Wall Attachment Device" - American Society of Mechanical Engineers, 1968.

"A Fluidic Acoustic Sensor" - Instrument Society of America, 1970 Fluidics Quarterly, 1971.

"A Long Range Fluidic Acoustic Sensor" - American Society of Mechanical Engineers, 1972. Fluidics Quarterly, 1973.

He was honored by the Fluid Power Society with the Design Award of the Year, 1972.

Adam C. Bell

Associate Professor of Mechanical Engineering at the State University of New York at Buffalo, Buffalo, New York, 14214. Undergraduate education in Nova Scotia, Canada: B.Sc., Dalhousie University, 1961; B.Eng. (cum laude), Nova Scotia Technical College, 1963. Graduate education at Massachusetts Institute of Technology, all in Mechanical Engineering: S.M, 1966, M.E., 1968, Sc.D., 1969. On the faculty of SUNY/Buffalo since 1968. Honors have included the Canadian Aeronautics and Space Institute Medal, 1962 and the SAE R.R. Teetor Award, 1970. Currently active in the ASME, Sigma Xi, and Tau Beta Pi. ASME activities include: Papers Review Chairman, Bioengineering Division, Member of Automatic Control Division Ad Hoc Committee on Industrial Participation, and ACD representative to the Fluidics Committee. Current research interests include: theory and application of bond graphs to systems modeling; fluidics; instrumentation for applications in mechanical testing, the scanning electron microscope, and bioengineering; dynamic modeling of earthmoving equipment and vibratory rollers; and computer aided assembly machines. During the academic year 1975-1976 the author will be working on the last of these on sabbatical at MIT.

Charles J. Bell, Jr.

Charles J. Bell, Jr. is presently Professor of Mechanical Engineering at Mississippi State University. He received a B.S. in Mechanical Engineering in 1949 from Mississippi State University, a M.S. in Mechanical Engineering in 1963 and a Ph.D. in 1965 from Georgia Institute of Technology. He holds membership in Tau Beta Pi, Pi Tau Sigma, Fluid Power Society, Sigma Xi, and Instrument Society of America. His technical areas of interest, research, and publications include automatic controls, fluid controls, vibrations, fluid mechanics, and thermodynamics.

Robert H. Bellman

B.S. Aero Engineering - University of Illinois, 1958

M.S. Engineering Sciences - University of Buffalo, 1974

Employed at Corning Glass Works and have worked in Fluidics since 1963. Work has included gate and circuit design. Won 2 Fluid Power Society design awards for Corning, and has been awarded 7 patents.

Charles A. Belsterling

Mr. Belsterling is currently Manager of the Electrical Engineering Laboratory of the Franklin Institute Research Laboratories in Philadelphia, Pa. His work includes directing and participating in all projects involving fluidics and fluid logic.

Mr. Belsterling has a technical background of more than 20 years in all types of feedback control and servo systems. In 1963 under the sponsorship of Harry Diamond Laboratories, he initiated fluidics research at The Franklin Institute and began a program in component characterization from the point of view of the control systems engineer. After joining Giannini Controls in 1964 he continued the program with support from the Army Aviation Material Labs and developed a complete unified approach to straightforward fluidic systems design. Beginning in 1965 he directed a program to apply fluidic devices and techniques to aircraft control and demonstrated the feasibility of aircraft stabilization without moving parts. In 1967 he became co-founder of Cutler Controls, Inc. with the responsibility for the development and production of a complete line of fluidic devices for the industrial market. During this period he expanded his research on fluidic device modeling into a full-length reference book, *Fluidic Systems Design*, published by John Wiley and Sons in 1971. Since returning to The Franklin Institute in 1971 he has been developing mathematical models for a variety of fluidic components and applying analog and digital computers in the design and analysis of fluidic systems.

Charles A. Belsterling (cont.)

Mr. Belsterling earned a B.S. degree in Electrical Engineering at Drexel Institute of Technology in 1951, and an M.S. degree in Electrical Engineering at the University of Pennsylvania in 1955, majoring in feedback control systems.

J. D. Black

Assistant manager of Fairline Furniture Pty. Limited, Sydney, Australia. He received his B.Sc. and B.E. degrees from the University of Sydney and his M.Eng.Sc. degree from the University of New South Wales, Australia.

He was employed as a research engineer at M.D. Research Company in Sydney from 1970 until he took up his present appointment in 1973.

Willis A. Boothe

Prior to his current assignment in the area of coal and oil gasification projects, Mr. Boothe was active in various aspects of fluid power control since joining the General Electric Company in 1950. A graduate of Carnegie Institute of Technology (BSME 1949, MSME 1950) and of General Electric's Fluid Mechanics "C" Course, he joined a predecessor laboratory to General Electric's Corporate Research and Development in 1953. There, he developed hydraulic and pneumatic controls for industrial, aircraft and marine applications. He has been active in fluidics since 1961 and holds more than thirty five patents for fluidic and fluid power control devices. He is a member of the American Society of Mechanical Engineers, and a registered Professional Engineer in New York State.

Romald Edward Bowles

Engineering Consultant, 2105 Sondra Ct. Silver Spring, Md. 20904, Born 13 Feb '24, B.S. '47, M.S. '48, Ph.D. '57 Univ of Md. Mechanical Engr. (Aero Optn Course) with Minors in Math & Physics.
AWARDS: '47 ASME Wash Sec Student Prize, '56 Diamond Ordnance Fuze Laboratories Fellowship, '60 Wash Academy of Sciences Outstanding Achievement Award for the Technical Sciences, '62 Dept of the Army R&D Achievement Award, '63 Pi Tau Sigma Honorary Membership, '65 National Fluid Power Assn Achievement Award, '66 The John Scott Medal.
PATENTS: Inventor or co-inventor of 53 U.S. Patents and 128 Foreign Patents with additional foreign and domestic patents pending.
MEMBERSHIPS: Fellow, Wash Academy of Sciences, Associate Fellow AIAA, Senior Member ISA, Member ASME, ADPA, MDSA, Sigma Xi The Scientific Research Society of North America, N.G.S., Pi Tau Sigma.
REGISTERED PROFESSIONAL ENGINEER, Maryland, Specialties- Mech Engr, Fluid Dynamics, Fluidics, New Product R&D.

Romald Edward Bowles (cont.)

EMPLOYMENT: '46 David Taylor Model Basin, '47-48 Univ of Md. College of Engr, '48-'50 Naval Ordnance Laboratory, '50-'54 The John Hopkins Univ. Applied Physics Lab, '54 Ordnance Missile Lab Redstone Arsenal, '54-'61 Diamond Ordnance Fuze Laboratories, '61 Bowles Engr. Co., '61-'73 Bowles Fluidics Corp., '73-present Engineering Consultant.

Rolf K. Brodersen

Mr. Brodersen received an MSEE in 1952 from the Technische Hochschule Karlsruhe (West Germany) and holds an MSIE (1959) from Columbia University, New York. From 1952 to 1954 he worked on microwave transmitter development at the Central Laboratories of Siemens and Halske in Munich, West Germany. During 1954 and 1955, Mr. Brodersen was development engineer at the Westinghouse Lamp Division in Bloomfield, New Jersey. In 1955, he joined the Kearfott Company in Little Falls, New Jersey, where he was employed until 1962 in various assignments covering inertial guidance and flight control components and subsystem design and development. Since 1962 he is a senior staff engineer (now Member, Professional Staff) at the Orlando Division of Martin Marietta Aerospace, engaged in research, application studies, and development of inertial sensors as well as of guidance and control subsystems and components. Since 1968, his work has been concerned with fluidic technology in tactical weapon system applications. At the present time, he is responsible for the development of two types of fluidic inertial gyros (under contract to the Naval Air Systems Command) and of a fluidic ejection seat sequencer (for the Naval Ordnance Station, Indian Head, Maryland). The author of eight technical papers, Mr. Brodersen holds six patents, and is a member of the IEEE.

Forbes T. Brown

Forbes T. Brown, a native of Newton, Massachusetts, spent the years 1952-1970 at M.I.T., including periods as undergraduate and graduate student, instructor, assistant professor and associate professor. Since 1970 he has been Professor of Mechanical Engineering at Lehigh University, Bethlehem, Pennsylvania. General interests include design, dynamic analysis and control of engineering systems. His research has involved primarily fluid systems, most particularly fluidics and fluid line dynamics, and secondarily the modeling and analysis of lumped and distributed-parameter systems. His first report on bistable fluidic amplifiers is dated June, 1959, six months before the announcement of the birth of fluidics by the Diamond Ordnance Fuse Laboratories (now HDL). He presently is engaged in teaching dynamic analysis and control, serving as Senior Member of the Executive Committee of the Fluids Engineering Division of ASME (where he was instrumental in starting the Journal of Fluids Engineering, and was the first ful-term Chairman of the Fluidics Committee), and doing research on the deterministic aspects (resonance) of the structure of turbulence of the flow in tubes with harmonic excitation.

Pah I. Chen

Pah I. Chen was born in Fukien Province, China, on April 4, 1938. He completed his undergraduate study in Taiwan where he was awarded a B.S. degree from Cheng Kung University in 1960. He came to the United States in 1962. Subsequently, he studied at Virginia Polytechnic Institute where he received his M.S. degree in 1963, and Ph.D. degree in 1966. He is presently an associate professor in the Engineering and Applied Science Department, Portland State University, Portland Oregon. He has been responsible there for establishing a Fluid Control Laboratory. He teaches courses in fluid mechanics, thermodynamics, heat transfer, and fluid control systems. Recently, he assisted the Oregon Museum of Science and Industry in designing a whole series of fluidic exhibits for permanent display at the Museum. He is a member of the American Society of Mechanical Engineers, and Sigma Xi Society. He is also a member and one of the founders of the Oregon Fluid Power Association. He is married and has one son.

William George Colborne

Title: Professor and Head of Mechanical Engineering Department

Education: Queen's University, B.Sc. in Mech. Eng. in 1948
Queen's University, M.Sc. in Mech. Eng. in 1960

J. H. Cole

Position: Associate Professor of Mechanical Engineering
University of Arkansas, Fayetteville, Arkansas

Education: B.S., M.S., and Ph.D. degrees in Mechanical Engineering from Oklahoma State University, 1958, 1963, and 1968 respectively.

Experience: 1968-Present. Teaching and Research at U of A. Courses include Fluid Logic, Hydraulic Control, Systems Dynamics, and Machine Design. Research efforts include fluid logic synthesis procedures development, hydraulic systems, and design projects. Also serve as consultant in controls, design, and analysis.

1964-1968. Senior Design Engineer for Rockwell International Corp., Tulsa Division.

1963-1964. Senior Design Engineer for General Dynamics, Fort Worth Division.

1958-1963. Engineer for American Airlines.

Professional Societies : Member ASME, SAE, ASEE, Sigma Xi, and Fluid Power Society.

Robert A. Comparin

R. A. Comparin received his B.S. in 1954, his M.S. in 1958, and his Ph.D. in 1960, all in mechanical engineering at Purdue University. As a graduate student at Purdue, he was also an instructor in the Mechanical Engineering Department. In the summers of 1953 and 1954 he was employed by the General Electric Company. From February 1960 until August 1962 he was employed in the Product Development and Research Laboratories of the International Business Machines Corporation. He was an assistant professor at the University of Main from September 1962 until June 1964. At that time he hoined the faculty of VPI and remained there as a professor in the Mechanical Engineering Department until June 1974. He was a consultant in fluidics for Corning Glass Works from 1963 until 1968, and has taught and conducted research in the fluidics and fluid mechanics area. Dr. Comparin is currently Chairman of the Mechanical Engineering Department at Newark College of Engineering.

Lyndon S. Cox

Lyndon S. Cox is a mechanical engineering graduate of the University of Maryland, a member of Pi Tau Sigma and Tau Beta Pi honor societies, and the product of over twenty years of diversified engineering experience. This experience includes tool design, product design, instrumentation and environmental testing at the Naval Gun Factory and the Harry Diamond Laboratories (HDL), with additional experience in radio-telemetry, nuclear weapons effects, and fluidics at HDL. He has served in fluidics as a researcher, a development supervisor, instigator of manufacturing technology programs, and as coordinator of the Army fluidic program.

Richard Deadwyler

Electronics Engineer

BSEE - ME(EE)

Mr. Deadwyler has worked on acoustic phenomena and fluidics for ten years in the areas of flueric signal mixing, pressure regulation, impedance, oscillators, amplifiers, speech amplification and transmission, and hydraulic fluidic compensation circuits. He has made original contributions in many of these areas. He developed a signal mixing technique to reduce high frequency sensor outputs and opened the field of fluerics to acoustic switching of jets. His study of fluid resistance has shown how lumped parameter resistance varies with temperature in the previously unknown area between the laminar and fully turbulent regimes. Recently he made a linearized lumped parameter analysis which shows that flueric oscillators can be made temperature and pressure insensitive. He has authored or coauthored a number of technical papers in these areas.

Tadeusz M. Drzewiecki

Mr. Drzewiecki (pronounced JRE-VIET-SKI) was born in London, England in 1943 of Polish emigre parents. His primary education was in England. He came to the U.S. in 1956 and completed his education in New York. He was graduated from The City College of the City University of New York with a Bachelor of Engineering (Mechanical) and a Second Lieutenants Commission in 1966. He was awarded the David B. Steinman Memorial Scholarship and continued his studies culminating in a Masters Degree in January of 1968. He continued his studies until June.

Mr. Drzewiecki's career in research started with National Science Foundation Apprenticeships during the summers of 1966 and 1967 where he conducted studies of two dimensional heat transfer with phase change. He worked as an engineering instructor in the Mechanical Engineering Department of CCNY and taught Thermodynamics, Heat Transfer and Gas Dynamics. In 1967 he obtained a position at the Harry Diamond Laboratories as a Research Mechanical Engineer in the Fluidic Systems Research Branch. In 1968, Mr. Drzewiecki entered active duty in the Army Corps of Engineers and was assigned for three years to the Harry Diamond Laboratories. Upon release from active duty in 1971, with the Army Commendation Medal for Meritorious technical service, he rejoined the civilian ranks of HDL. In 1972 he was awarded the HDL Hinman Award for Technical Excellence for his contribution to Fluidics. Mr. Drzewiecki is presently an Acting Research and Development Supervisor in the Fluidic Systems Research Branch. He is the author of over 25 technical papers and the holder of four U.S. Patents in the field of fluidics. He is married, has a four year old daughter, and is presently residing in Colesville, Maryland.

Edward R. Durlak

Education:

BSME, University of California (LA), 1968
MSME, University of California (LA), 1971

Experience: Four years at Rocketdyne Corp. in area of rocket system performance analysis, acceptance testing, and component integration. Three years at Civil Engineering Laboratory, NCBC, in areas of structural platforms, VLF antenna insulators, energy storage systems, fluidics, and solid waste disposal.

Richard H. Fashbaugh

Education:

BSEE, University of Michigan, 1949
MSEM, University of Michigan, 1950
Ph.D., University of Colorado, 1969

Richard H. Fashbaugh (cont.)

Experience: Five years at Civil Engineering Laboratory, NCBC working in hydraulic fluidic device development and nuclear blast wave propagation studies. Five years at the Martin Marietta Corporation where responsibilities included missile propellant system design and testing and propulsion system transient flow analysis. Seven years at the Allison Division of General Motors associated with gas turbine mechanical design and high temperature gas flow and heat transfer analysis.

Solomon S. Fineblum

George Washington University, B.M.E., 1950, M.S.E., 1962. At Convair Aircraft, aircraft engine installations and fuel and oil system designs. Later at North American Aviation, I performed aircraft propulsion and colling R&D, developed an optimization method for aircraft fluid systems, performed two-phase flow analysis and developed a fuel-air separator. I did techno-economic forecasting, developed test methods and plans and general fluid-dynamic analysis. Developed aircraft air conditioning systems and analyzed swimming animal propulsion.

At RANCO, Columbus, Ohio, I performed research and feasibility studies on refrigeration and air conditioning control systems, and fluidics R&D.

At Bellcomm, Washington, DC, I performed thermal balance and mass-flow analysis for space craft and developed theory for flame propagation in oxygen-enriched atmospheres.

At Bell Laboratories, I analyze cooling requirements and cooling systems including chilled water, air flow and system reliability as well as potential solar energy applications. Patents in aircraft cooling and refrigeration controls. Published papers are on techno-economics, vortex flow and flame propagation.

Milton E. Franke

Professor Milton E. Franke currently teaches and conducts research mainly in the areas of aerodynamics, gas dynamics, fluidics, acoustics, and heat transfer. He received his BME from the University of Florida, his MSME from the University of Minnesota, and his PhD from The Ohio State University. He served on active duty with the Air Force from 1952 to 1956 in the Propulsion Laboratory at Wright-Patterson Air Force Base, Ohio. His industrial experience was at Westinghouse in 1952 and at DuPont from 1957 to 1959. Since 1959, he has been a member of the faculty at the Air Force Institute of Technology where he presently holds the rank of Professor Mechanical Engineering.

S. B. Friedman

Dr. Friedman received his education in the United States and Canada. He has been employed in manufacturing and automation, product design, and engineering management for more than twenty years, and was a pioneer in the application of high speed pneumatic components to the digital control of production machinery. He holds basic patents in both the controls and liquid fluidic areas.

He joined the faculty of Wm. Rainey Harper College as Head of Mechanical Engineering and Technology in 1969, and served in that capacity and as a consultant to industry until 1974. He is currently Associate Professor in the School of Applied Science at Miami University, Oxford, Ohio, as well as Director of Research for Engineering Technology.

R. N. Gottron

Mr. Gottron received a BS in Military Science from the US Military Academy in 1955. He received an MS in Engineering at Purdue University in 1960 and completed 12 hours of graduate work at Maryland University. He also holds a Certificate of Completion from the Von Karman Institute Brussels, Belgium, 1968.

Mr. Gottron has had six years of fluidic research experience and six years of fluidic development work. For the past five years he has been branch chief of the Fluidic Systems Development Branch at the Harry Diamond Laboratories (HDL), Washington, DC. He has authored numerous reports in the field of fluidics and holds four patents in the technology.

J. Grant

First worked in the Engineering Division of British Broadcasting Corporation, after service in R.A.F. took M.A., B.Sc. in Mathematics and Natural Philosophy at Edinburgh and London Universities. After graduation he worked on aircraft control and radar systems and the development of the first commercially successful numerically controlled machine tools. He joined U.K.A.E.A. in 1957 to work on dynamics, accident analysis and control of nuclear reactors. In 1965 he began investigation on new methods of reliable control for nuclear reactors and chemical plant, this included the design of prototype reactor computer systems and the design of fluidic process control systems to eliminate failure prone valves, actuators and pumps. He is currently visiting lecturer to the University of Manchester and Senior Research Fellow at the University of Bradford.

Kenneth B. Haefner

Education: BEE and MSE, Union College, 1955 and 1964

Experience: Mr. Haefner is presently heading a program sponsored by the Goddard Space Flight Center for the development of advanced fluidic sounding rocket attitude control system. He has recently completed a development program for applying fluidics to an aircraft environmental control system for the U.S. Air Force Belvoir. He has been involved in the field of fluidics for a period of 7 years in various development programs involving the application of fluidics to Rankine cycle controls. CF6 vibration shutdown systems, and missile autopilots. Additional project work has also included the development and fabrication of a fluidic Approach Power Compensator for the Naval Air Development Center.

Prior to joining the Fluidics Operation he was a Systems Engineer in the Research and Development Center, engaged in transportation systems studies in the simulation and design of start-up and load controls for large steam turbines, the study of models for information and organization systems, and the analysis and modeling of complex control systems.

Mr. Haefner's writings have included co-authorship of a published paper on Self-Adaptive Flight Control through Frequency Regulation, presented at the WESCON Conference in August 1961. He is a member of Sigma Xi honorary science society and the Institute of Electrical and Electronics Engineers.

Y. Hara

Y. Hara was born 30 June 1934. Upon graduation from Osaka Prefectural University in March 1959 he joined the Government Mechanical Laboratory of M.I.T.I. (Now called the Mechanical Engineering Laboratory).

Until 1961 he did research on unstable phenomena related to wing surfaces (in the transonic region). In 1962 he began research on fluidic elements. More recently (about 1970) he has investigated fluidic control systems that can be used in the sea.

His fluidic publications include:

1) S. Ozaki, Y. Hara and T. Orita, "Basic Guide to Fluidic Elements," Nikkan Kogyo, 1965.

2) Y. Hara and T. Ogawa, "Some Experiments of the Unsteady Vibrations in the Transonic Region," Journal of Mechanical Engineering Lab., July 1963.

3) Y. Hara et al, "Study on Fluid Logic Element (1) - Fluid Oscillator without Moving Parts," Journal of Mechanical Engineering Lab., Vol. 10, No. 2, 1966.

Y. Hara (cont.)

4) Y. Hara et al, "Study on Fluid Logic Elements (II)," Journal of Mechanical Engineering Lab., Vol. II, No. 2, 1966.

5) Y. Hara et al, "Output Characteristics of Wall Attachment Elements," 3rd Cranfield Fluidics Conference, 1968.

6) Y. Hara et al, "Attitude Control System of an Underwater Body using Liquid Fluidic Elements," HDL Fluidic State-of-the-Art Symposium, October 1974.

Arthur Hausner

Arthur Hausner graduated from Brooklyn College with a B.S. in physics in 1951 and joined the staff of the Ordnance Divisions of the National Bureau of Standards. He transferred with those divisions when they became the Diamond Ordnance Fuze Laboratories (now the Harry Diamond Laboratories) in 1953, and was engaged in the theory, design, development, and testing of arming mechanisms from 1951-1959. His interest shifted to analog and digital simulation and computing techniques, a field he has been in from 1959 to the present.

An author of 1 patent, numerous technical reports and papers, Mr. Hausner also published a book on analog and analog/hybrid computers in 1971. He is a member of the Association for Computing Machinery, The Institute of Electronic and Electrical Engineers, and the Simulation Councils, Inc.

James O. Hedeen

Education: BS - Mech. Engr. 1959, University of Minn.
MS - Mech. Engr. 1961, University of Minn.
MBA 1971, University of Minn.

Experience - 13 years experience in the area of fluidics at Honeywell's Government and Aeronautical Products Division, working primarily in fluidic component development and the application of fluidics to flight control systems. Currently responsible for the following engineering programs:

The development of a fluidic stability augmentation system for the Sikorsky UTTAS helicopter

The development of an advanced hydraulic fluidic stabilization system for the UH-1 helicopter

A study of techniques to provide a hydraulic fluidic primary flight control system as a back-up to fly-by-wire control.

Richard F. Hellbaum

Richard F. Hellbaum received his degree in Physics from Kansas State Teachers College in 1962 and attended graduate school at the University of Oklahoma. He has worked at Langley Research Center, NASA since 1964 in fluidics specializing in rate sensing, fabrication, and amplification. He holds patents and has published papers in these areas.

Leslie R. Hester

Leslie R. Hester is presently Associate Professor of Aerophysics and Aerospace Engineering at Mississippi State University. He received a B.S. in Aeronautical Engineering in 1952 and a M.S. in Aeronautical Engineering in 1953 from Mississippi State University. He did graduate study at the University of Texas, Austin from 1965-67 on a National Science Foundation Faculty Fellowship. He holds membership in American Institute of Aeronautics and Astronautics, Tau Beta Pi, Kappa Mu Epsilon, Sigma Xi, and Sigma Gamma Tau. His technical areas of interest, research, and publications include guidance and control of flight vehicles, optimization techniques, fluidic control systems, and instrumentation.

E. C. Hind

Senior lecturer in the School of Mechanical and Industrial Engineering at the University of New South Wales, Australia. He received his diploma in mechanical engineering from the Sydney Technical College and his B.E. and M.E. degrees from the University of New South Wales.

After holding various positions in private industry over a period of eight years, he joined the university of New South Wales in 1953. He was appointed lecturer in 1956 and senior lecturer in 1964. He commenced research on pneumatic control system components in 1958 and has worked on fluidic systems and components since 1963. Currently his main teaching duties are in the field of Automatic Control.

Thomas S. Honda

Education: BS in Agriculture, Rutgers University, 1951

BSME Rutgers University, 1952

MSME Union College, 1962

Currently responsible for project leadership of fluidic component and control system development programs for the Specialty Fluidics

Thomas S. Honda (cont.)

Operation. Has been associated with Specialty Fluidics Operation since its organization in 1970.

Previously was with the Corporate Research and Development Center of General Electric Company working on fluidic and fluid control devices and circuits.

Prior to joining the Corporate R&D Center, was with General Electric's Light Military Department where major experience was in the development of hydraulic servactuation systems for aircraft flight control. Was also project leader on an Air Force cryogenic refrigerator development program. Also contributed to the F111 aircraft redundant servoactuator development and to an Air Force liquid metal servo development program.

Joseph M. Iseman

Mr. Iseman received a BS in physics from George Washington University in 1961, an MSE in Space Science and Applied Physics from The Catholic University of America in 1969, and will receive a PhD in Mechanical Engineering from Oklahoma State University in December 1975. He joined the Fluid Systems Research Branch of Harry Diamond Laboratories in 1962 and has investigated and authored and coauthored papers on a variety of fluidics components and devices including angular velocity sensors, temperature sensors, and digital logic devices and systems.

Recently Mr. Iseman has been concerned with modeling and simulating passive and active fluidic components. He has concerned himself with evaluating equivalent circuit models relative to experimentally validated reference models. He has adapted two digital network analysis codes (SLIC and NET-2) to fluidic systems. He is a member of ASME.

Paul L. Jacobs

Paul L. Jacobs received an AB in English from Stetson University in 1964, a BME from the University of Florida in 1965, an MSME from MIT in 1966 and a PhD in Mechanical Engineering from the University of Florida in 1969. He did graduate work in fluid dynamics at MIT, analyzing wave propagation from high speed trains entering tunnels utilizing the hydraulic analogy to compressible fluid flow. At the University of Florida, he worked in the area of cryogenic heat transfer, determining anisotropic thermal conductivity of single crystal CdSe over the cryogenic temperature range. Dr. Jacobs served two years in the Army, one as an engineer in the LANCE Missile Project Office at Redstone Arsenal and one as an action officer for mechanical maintenance at US Army Headquarters in Vietnam. He is currently employed in the Guidance and Control Directorate, US Army Missile Research, Development and Engineering Laboratory, US Army

Paul L. Jacobs (cont.)

Missile Command, where he is a team leader for missile control systems and is the technical director of the high acceleration terminal homing (HATH) technology effort.

T. Jansen, P. Eng

Native of Heerlen, Holland. Project Engineer, Standard Products, Stratford, Ontario. B.S. (1965) and M.S. (1969) in Mechanical Engineering from Michigan Technological University.

Master's thesis on pressure recovery of laminar jets published in "Fluidics Quarterly".

Research Engineer, Fluidic Controls Division, Pitney-Bowes Inc., Stamford, Conn.

Senior Engineer and Chief Engineer, Fluidic Controls Division, Automatic Switch Company, Florham Park, NJ.

Patents on miniature fluid amplifier and temperature compensating device.

Presently Lecturer (Applied Thermodynamics), College of Fisheries, Navigation, Marine Engineering & Electronics, St. John's, Newfoundland, Canada.

Wife Frances H., two children, David and Marian.

Joseph M. Kirshner

Chief, Fluidics Systems Research Branch, HDL, Washington, DC. Professorial Lecturer in Engineering, George Washington University. Organized (and first chairman of) ASME Fluidics Committee and Government Fluidics Coordination Group. Author or coauthor of approximately 20 papers and 2 books on fluidics and approximately 20 papers on other topics. Listed in American Men of Science, Who's Who in the South and Who's Who in Automatic Control.

Yau-Hwang Lee

Yau-Hwang Lee was born in Taiwan, China, on October 20, 1946. He graduated from the National Chung Hsing University, Taiwan, with a B.S. degree in applied mathematics. He came to the United States in 1972 and enrolled in Portland State University where he is finishing up his Master of Science degree. He is presently a research assistant in the Physiology Department, University of Oregon Medical School, Portland, Oregon.

H. P. Lin

Dr. Lin graduated with a Ph.D. in Mechanical Engineering from the University of Missouri in Columbia, Missouri in May, 1973. Since July, 1973 he has been employed as an engineer in the area of nuclear and fossil fuel power plant system design by Stone & Webster Engineering Corporation. He is an associate member of Sigma Xi.

Sui Lin

Sui Lin is Assistant Professor in Mechanical Engineering Department at Concordia University in Montreal, and a Registered Professional Engineer and a member of the EIC, CSME and DGLR. He received the Dipl.-Ing. and Dr.-Ing. degrees from the University of Karlsruhe, West Germany. He was Research Associate at the Institute for Refrigeration and at the Institute for Fluid Mechanics and Fluid Machinery at the University of Karlsruhe, and also at the Institute for Aerospace Studies at the University of Toronto. His teaching and research fields are heat transfer, thermodynamics, fluid mechanics and fluid control. He is the author of more than 30 technical papers.

Francis M. Manion

Francis M. Manion is a R&D Supervisor in the Fluidic Systems Research Branch at HDL and is a recognized authority in the fluidics field. He has performed basic, applied research and supervised fluidic development projects since 1960 and has many publications and patents to his credit covering almost every aspect of the field. His interests include fluid mechanics and control system analysis & design and he has contributed to both analytically and experimentally.

Charles A. Martin

Bachelor's Work - Wayne State University, Aeronautical Engineering

Master's Work - Wayne State University, Engineering Mechanics
Thesis: "Navigational Trajectories from Mars to Earth"
Doctoral Work - Wayne State University, Mechanical Engineering Science
Dissertation: "Variable Threshold Logic and its Application to Digital Fluid Controls.

Work Experience:

Ford Motor Company	Research & Engineering Center, Product Engineer 1962-1963	
LTV Michigan	Product Design Engineer 1964	
University of Detroit	Engineering, Mechanical Dept.	1964 - 1965
General Motors Institute		1965 - present

Charles A. Martin (cont.)

Publications:

Besides the papers referenced in the symposium paper 111-159, an article "Aerodynamic Sailing" is forthcoming in late 1975 to be published in Scientific American.

H. R. Martin

Educated in Britain, Dr. Hugh R. Martin, gained practical experience in engineering with the aircraft manufacturer, Short Bros. and Harland Limited, where he worked for ten years on the design and development of hydraulic control systems for both aerospace and industrial applications.

After joining the staff of Queens University, Belfast, he became founder and joint director of the Low Cost Automation Centre for Northern Ireland. This allowed Dr. Martin to continue his interest in industry as a consultant. Apart from extensive research activities in fluid control system, Dr. Martin has been active in developing flow measuring equipment, and in noise analysis and control. He is currently Associate Professor in Mechanical Engineering at the University of Waterloo, Ontario, Canada.

R. W. Mayne

Dr. Mayne was born March 14, 1942. He received a B.S. from the State University of New York at Buffalo in 1963, and M.S. from the Georgia Institute of Technology in 1965 and the PhD from Pennsylvania State University in 1971. From 1964 to 1967 Dr. Mayne was employed as a Development Engineer for the Eastman Kodak Company where he worked in the design of theremal systems and in the development of photographic equipment. Since 1970, he has been an Assistant Professor in the Department of Mechanical Engineering, State University of New York at Buffalo teaching in the design and systems area. His present research interests include fluid power control, the performance of manual control systems, and the application of optimization techniques to engineering design and manufacturing problems.

Dr. Mayne is a member of Tau Beta Pi and Phi Kappa Phi honoraries, the American Society of Mechanical Engineers and the American Association for the Advancement of Science.

Alan T. McDonald

Education:

BSME, Purdue University, June 1960
MSME, Purdue University, June 1962
Ph.D., Fluid Mechanics, Purdue University, January 1965

Alan T. McDonald (cont.)

Background:

Dr. McDonald was on the faculty of the University of California at Davis for three years. There he performed analytical and experimental research on turbulent flow of drag reducing solutions of high polymers. In addition, he helped to develop laboratories in fluid mechanics and engineering principles, and developed and taught graduate courses in boundary-layer theory and turbulence.

Since returning to Purdue in June 1967, Professor McDonald has continued research in internal aerodynamics, diffuser flow and hydrodynamics. He developed a water table facility for fundamental work in fluidics, and has directed work on design and performance of diffusers with distorted inlet conditions and with low Reynolds number inlet flows.

Professor McDonald has been active in working with industry. As a consultant to Westinghouse Electric Corporation in the areas of hydrodynamic design and internal aerodynamics, he directed a wind-tunnel test program to develop a low-drag vehicle with boundary-layer control by suchtion. He continues to contribute to this program as a member of hydrodymaics advisory panel working for RAND Corporation.

Ernest F. Moore

Major Ernest F. Moore is presently assigned to the Flight Control Division of the Air Force Flight Dynamics Laboratory, and serves as program manager of research effects concerning integration of flight and fire control systems for USAF fighter aircraft. Prior to the AFFDL assignment, Major Moore served as program manager for Southeast Asia projects at the Aeronautical Systems Division of the Air Force Systems Command. In 1967-68, he was assigned as crew member, EB-66 aircraft, and flow 100 combat missions in Southeast Asia. Major Moore was awarded the degree of BSME from Bradley University in 1958, an MSAE from the Air Force Institute of Technology in 1967 and is presently working on his PhD.

Hal L. Moses

H. L. Moses received his B.S. in mechanical engineering at VPI in 1960, his S.M. at MIT in 1961, and his Ph.D. at MIT in 1964. He wrote his doctoral thesis in the basic fluid mechanics area as a research assistant in the MIT Gas Turbine Laboratory, and remained there as an Assistant Professor and post-doctoral fellow until July, 1966. At that time, he joined the Fluidics Research Department of Corning Glass Works, where he was employed until April, 1969. Since September, 1969, he has been an associate professor in the Mechanical Engineering Department at VPI, where he has taught and conducted research in basic fluid mechanics, turbomachinery, and fluidics.

Harold N. Ott

Harold N. Ott is an electrical engineer in the Electro-Mechanical Equipment Branch, Engineering Specifications and Standards Department, Naval Air Engineering Center, Lakehurst, NJ. After receiving a BSME from Lafayette College in 1939 he was employed in aircraft engine design at Pratt and Whitney Aircraft, and also at the Jacobs Aircraft Engine Company. He took graduate work in aeronautical engineering at the University of Connecticut under a Pratt and Whitney Aircraft program. In 1942 he became an aeronautical power plant test engineer in the US Navy Aeronautical Engine Laboratory at the Naval Air Engineering Center, Philadelphi, Pa., and in 1964 transferred to tbe Engineering Specifications and Standards Department.

Dharam Pal

Education:

BSME, Thapar Institute of Engineering and Technology, India, 1965.
MSME, University of California, (Berkeley), 1967

Experience: Civil Engineering Laboratory, NCBC, for seven years. Work experience included blast resistant ventilation fan development, research in fluidic devices for mixing two fluids, experimental determination of hardness of mechanical equipment, and fluidic oil-water separator development.

G. A. Parker

He was educated at King Edward VI Grammar School, Nuneaton and Birmingham University, graduating in Mechanical Engineering in 1957. Subsequently he hoined Hawker Siddeley Dynamics working on Fluid Control Systems for Guided Weapons and then returned after three years to Birmingham University to study for a Ph.D. in the area of A.C. flow in oil hydraulic transmission systems.

For a time he worked with Cincinnati Milling Machine Co. in the States on advanced machine tool control systems for machine tools before returning to Birmingham University as a Lecturer in Control Engineering. In 1968 he took up his present appointment as Reader in Mechanical Engineering at the University of Surrey, Guildford, U.K.

Apart from an active research interest in fluidics, he is currently interested in system identification, adaptive electro-hydraulic control systems and fluid regulators.

Carl G. Ringwall

Mr. Ringwall graduated from North Dakota State University in 1942 with a B.S. in Electrical Engineering. He joined General Electric Company in 1947, and has twenty seven years of experience in electromechanical, electronic and fluidic control systems and inertial components. He is the holder of twenty patents, eighteen of them directly related to fluidic technology.

Gary L. Roffman

Gary L. Roffman received his B.S. degree in Physics from the George Washington University in 1962 and has worked for the Harry Diamond Labs in the Fluidics Research Branch since that time. He is a member of the ASME and has written papers on a wide variety of fluidic subjects including vortex rate sensors, a fluidic analog computer, compensation circuits, linear flow restrictors, speech amplification, high frequency amplifier measurements and the simulation of digital and analog fluid amplifiers.

Eugene E. Rowell, III

E. E. Rowell received his B.S. in 1973 and his M.S. in 1974 in mechanical engineering at Virginia Polytechnic Institute and State University. As a student at VPI, he participated in the NSF Undergraduate Research Program and began an investigation of contamination in fluidic devices. He received a graduate research assistantship to continue this work, under the sponsorship of the Harry Diamond Laboratories, and completed his M.S. program in the summer of 1974. At that time he accepted his present position with the Dow Badische Company.

David E. Scesney

1971 B.S. - Engineering from the State University of New York at Buffalo.

Quality Control Engineer from 1963 to 1972 with GTE Sylvania. Involved with manufacture of electronic systems for military use. Specified testing and failure analysis of electronic components.

From 1972 to present with Corning Glass Works Fluidic Products Department as Equipment Engineer. Development of fluidically controlled bag manufacturing machine.

H. M. Schaedel

2 March 1939	born in Vienna (Austria)
1949 - 1958	attendance of the COUVENgymnasium in Aachen
1958 - 1964	studies in electrical engineering (communication-engineering) at the Technische Hochschule in Aachen (technical university). Final examination as Diplomingenieur.
1 April 1964 - 31 March 1965	research engineer at Dr. Hans Boekels & Co. Aachen, Electronic Precision Measuring Techniques
1 April 1965 - 30 September 1971	research associate at the Institute for Communication Equipment and Data Processing of the TH Aachen. Field of activity: Fluidic components and networks.
13 December 1968	examination for a doctor's degree. Thesis on theoretical and experimental investigations on transmission lines and lumped components in fluidics.
1 November 1969 - 30 September 1971	head of the fluidics research group
1 October 1971	lecturer at the Fachhochschule Koln (professional school) in the department for communication engineering. Field: Control engineering and digital electronics.
20 December 1973	appointment to professor at the FH Koln
since winter-semester 1971/72	invitation to lecture on Fluidics in the department for electrical engineering of the TH Aachen
since 1 January 1973	Member of the Board of Technical Editors of "Fluidics Quarterly"

About 30 papers on fluidics. Main interest in fluidic circuit design and control engineering.

Albertus E. Schmidlin

Albertus E. Schmidlin is a Senior Research Scientist in the Concepts and Effectiveness Division of the Nuclear Development and Engineering Directorate, US Army Picatinny Arsenal, Dover, New Jersey. For the past five (5) years he has been engaged as principal investigator in several development projects utilizing fluidic components and systems for safing and arming munition systems. Before joining Picatinny Arsenal he was engaged for six (6) years in the Research Center at

Albertus E. Schmidlin (cont.)

Singer-General Precision, Inc., as Manager and Principal Staff Scientist of the Fluidics Department, responsible for the conception, planning, direction and control of applied research projects in fluid dynamics and heat transfer related to aerospace guidance and control hardware.

Earlier he was engaged for twenty (20) years at Walter Kidde and Company, Inc. in the development of fluid power and control equipment for aerospace vehicles. In particular he was responsible for the development of high pressure (3000 psi) pneumatic and mechanical equipment for airborne applications.

His educational background includes an M.E., M.S., and Sc.D. degrees in mechanical engineering, from Stevens Institute of Technology. He was elected to Tau Beta Pi and Sigma Xi societies, is a licensed Professional Engineer in the State of New Jersey, and is listed in Who's Who in the East, Vol. 8 and the 12th edition of American Men of Science. He has been a member of the American Society of Mechanical Engineers for 35 years and is active in the Automatic Control Division, holding offices in the Fluidics Committe as Papers Review Chairman, Chairman and Honors Chairman, consecutively. He is the new member of the Executive Committee of this Division effective July 1, 1975. He is also a member of the Society of Automotive Engineers and is Chairman of the Fluidics Panel of Committee A-6, Fluid Power and Control Technologies.

He has published numerous articales and papers and made presentations in his field and is the holder of 17 patents. He is active in the Stevens Alumni Association where he held many posts and is presently engaged as President for the '74-'75 period.

Walter R. Schurman

Walter R. Schurman is a graduate of Sinclair College, Dayton, Ohio, 1956 and has held positions at Harris Seybold Corp., Avco Corp., and Cooke Electric Corp. Mr. Schurman is currently a Senior Engineer at Mound Laboratory, which is operated by Monsanto Research Corp., for the United States Atomic Energy Commission in Miamisburg, Ohio.

Mr. Schurman has been active in Fluidics since 1969 and has designed and built numerous fluidic control systems for inplant use.

Mr. Schurman authored and presented technical papers at the Fifth Cranfield Fluidics Conference 1972; the winter annual meeting of the ASME 1972; the Eighth and Tenth Explosive Safety Engineering Conference 1972 and 1974, and at the recent Fluidics State of the Art Symposium, 1974.

Walter R. Schurman (cont.)

Mr. Schurman is also active in other fields and has authored technical papers and journal articles on such subjects as Injection Molding, Ultrasonic Assembly and Electrically Conductive Elastomers. Mr. Schurman is the holder of a patent on a flexible electrical connector which he developed at Mound Laboratory.

C. N. Shen

C. N. Shen, Mechanical Engineer, (Consultant) Watervliet Arsenal; Professor, Electric and Systems Department, Rensselaer Polytechnic Institute; Visiting Professor of Mechanical Engineering, Massachusetts Institute of Technology 1967-68; Assistant Professor, Dartmouth College 1954-58; B.S. National Tsing-Hua University 1939; M.S. and Ph.D. University of Minnesota 1950 and 1954, respectively; Member: ASME, AIAA, ANS, ASEE, ISA and Sigma Xi; Biographee: Who is Who in America, American Men & Women of Science; 60 technical papers in fields, co-author of book "Optimal Control of Nuclear Reactor"; Arrangement Chairman, Joint Automatic Control Conference at Rensselaer Polytechnic Institute 1965; ASME representative to the Application Committee of AACC 1972.

Akira Shimizu

Akira Shimizu was born in Shimonoseki, Japan, on November 14, 1939. He received the BE and ME degrees in Mechanical engineering from Hiroshima University, Hiroshima, Japan, in 1963 and 1967, respectively. Since 1967, he is with the department of Industrial and Mechanical engineering, Okayama University. His main interests are in fluid dynamics in fluidics, and fluidic systems.

Henrik H. Straub

BSAE (1962), University of Maryland; MS Engineering Science (1965) George Washington University.

In 1966 Mr. Straub joined The Boeing Company and conducted studies on fluidic missile control system applications. While assigned to a missile development program he developed a complete simulation of the missile electrohydraulic fin actuation system, including a pump, gas generator, and servo actuator. He was responsible for numerous dynamic analyses and tests of control systems applicable to proposal efforts and as part of in-house research. He developed a hybrid-fluidic rate sensor in an application study for the stability augmentation of the SST. On his assignments in the Landing Gear Research Group, he was responsible for the simulation of various brake control systems, the thermal analysis of the 737 brake and the breadboard development of

a pneumatic-fluidic antiskid system. Presently he is assigned as group leader to several landing gear system studies. Prior to joining Boeing, Mr. Straub worked at the Harry Diamond Laboratories in Washington D.C., where he was responsible for the development of fluidically-controlled medical devices such as a blood pump, automatic respirators, and an artificial heart. Mr. Straub holds one patent related to a fluidic application and has taught courses on the new technology on several occasions.

R. E. Strong

He obtained a batchelors degree in electrical engineering at Queen Mary College, University of London. He is currently a senior engineer in the Windscale plant with particular interests in safety and reliability. He became aware of "power fluidics" in 1972 and as a result has introduced several fluidic flow handling systems in the plant.

Robert J. Stuart

Mr. Stuart was born June 1, 1947. He received his B.S. degree in Mechanical Engineering from the State University of New York at Buffalo in 1970. After studying under a National Science Foundation grant, he received his M.S. degree in Mechanical Engineering, also from the State University of New York at Buffalo, in 1973. He is currently employed as a design engineer at the Zinsco Electrical Products Division of G.T.E. - Sylvania in Hampton, Virginia. Mr. Stuart is a member of the American Society of Mechanical Engineers.

Trevor G. Sutton

Education:

Higher National Certificate in Mechanical Engineering 1962
Higher National Certificate in Aeronautical Engineering 1963
From Royal Aircraft Establishment Technical College,
Farnborough, England

Experience:

1963 - Mechanical Engineering and Design of Navigation Systems
1964 - Mechanical Design of Wind Tunnel Models and Drone Wings
1964-
1966 - Fluidic Component Research and Development at Aviation Electric, Montreal, Canada
1966 - Fluidic Component and Systems Development at AiResearch, Phoenix
Presently Assistant Project Engineer, Fluidic Systems Group at AiResearch, Phoenix

N. Syred

Born in London, 1944. He obtained a B.Eng. degree in Mechanical Engineering at the University of Sheffield and then worked on vortex amplifiers for flow control in the same department until 1969 when he was awarded the degree of Ph.D. From 1969 until 1974 he worked as a research fellow in the department of Chemical Engineering and Fuel Technology investigating turbulent wake-flows in combustive systems and instability in solid propellant rockets. In September 1974 he became a lecturer in the department of Mechanical Engineering at the University of Wales, Cardiff. His current interests are fluidic flow control and combustion aerodynamics.

Charles K. Taft

Charles K. Taft was born in Cleveland, Ohio on July 24, 1928. He received a B.A. degree from Amherst College in 1951 and a B.S. degree at M.I.T. in 1953. In 1955 he was awarded the M.S. degree and in 1960 the Ph.D. at Case Institute of Technology.

In 1953 he joined the Warner and Swasey Company. In 1954 and 1955 he worked with Dr. D. P. Eckman at Case in the development of an electro-hydraulic servosystem with ultra-high frequency response for Warner and Swasey. In 1956 and 1957 he developed an electro-mechanical feed drive system for the Warner and Swasey numerically controlled turret lathe. In 1960 he rejoined Warner and Swasey as Chief Servo Engineer after completing his graduate work at Case.

In 1961 he joined the faculty at Case Institute of Technology as Assistant Professor of Engineering. At Case he supervised research in fluidics, electromechanical control, and digital control. The fluidics program was supported by Harry Diamond Laboratories and a group of eight industrial sponsors.

In 1967 he became Professor of Mechanical Engineering at the University of New Hampshire where he is working on fluid control and digital feedback systems design.

Dr. Taft has published over 60 papers, has patents in the field of automatic control, and has published a text with J. B. Reswick entitled "Introduction to Dynamic Systems".

Minoru Takagi

Minoru Takagi was born in Tsuruga, Japan, on April 1, 1943. He received the BE degree in applied physics from Fukui University, Fukui, Japan, in 1966. Since 1971, he is with the department of Industrial and Mechanical engineering, Okayama Univeristy, Okayama, Japan. His main interests are in fluidics.

Ernest A. Taylor, Jr.

Graduated from Plant High School, Tampa, Florida, in 1936. Electric motor rewinder and repairman, Tampa Armature works, to 1939. Became an electrician in the Tampa Shipyard, transferring to Ingalls Shipbuilding Company, Pascagoula, Mississippi in 1940. In that summer, started to Georgia Tech, continuing in the shipyard in the summers, except for 1943 when worked a full year, as electrician, leaderman, and foreman. In 1943, joined the Ship Repair Unit of the Navy as First Class Electricians Mate, later promoted to Chief Electricians Mate. Served on an Auxiliary Repair Lighter in four invasions in the Pacific to the end of WW II. Completed Georgia Tech with a B.S. of EE. in 1948. Went to work with Phillips Petroleum Company, Bartlesville, Oklahoma, as a design engineer, with one year as field engineer in a refinerty. Went with Electrical Equipment Company, Augusta, Georgia in 1951. In 1952, went with Patchen and Zimmerman, Consulting Engineers, Augusta, Georgia, doing civil, electrical and mechanical design, with one year in the field as an instrument inspector. In 1956, went with the Chemstrand Company, Decatur, Alabama, which later became the Monsanto Textiles Company. First job was the major electrical design for an experimental nylon spinning machine. Primary responsibility has been developing equipment and processes in the Acrilan Development Department. The last seven years has involved development of equipment utilizing the flow of fluids through nozzles in textile machinery. The similarity to fluidic flow patterns has led to interest in the study of fluidics and application of some of the flow phenomena. Winner of the 1972 Norbett P. No-No Fellowship Award from the Fluidics College of Practical Knowledge, sponsored by Corning Glass Works. Member of the IEEE, and the Fluid Power Society. Have eighteen United States Patents and many foreigh patents. Listed in Who's Who in the South and Southwest, 1965-66, Dictionary of International Biography, 1967, Two Thousand Men of Achievement, 1969 and 1971 and others.

Stephen M. Tenney

Born 15 July 1947 in Washington, DC. Educated in Arlington County, Virginia public schools. Attended George Mason College of the University of Virginia in the pre-engineering program. Finished bachelors program at the George Washington University graduating with a Bachelor of Science in Mechanical Engineering in 1970. Joined the Fluidic Systems Development Branch of the Harry Diamond Laboratories in August 1970. Worked on programs including the fluidic generator, nuclear hardness tests and fluidic mail handling. In September 1973 transferred to the HDL Fluidics Systems Research Branch to be a part of an investigation of a fluidic fuel injection system. Married in 1969 and has a son and daughter, lives in Rockville, Maryland.

R. V. Thompson

Dr. Thompson's career covers a broad spectrum of involvement in

R. V. Thompson (cont.)

both theory and application. He has been responsible for original research in the Marine, Aerospace and associated industries. Dr. Thompson served his apprenticeship at Chatham Naval base where he completed the four years Upper School of the Royal College.

He was employed by British Aircraft Corporation, Guided Weapons Division, as a Missile Engineer for several years; obtained a Masters degree for research on Naval gun aiming computers and subsequently led the Controls Department of YARD Limited, Scotstoun. For three years he lectured at Strathclyde University in Dynamics and Control and obtained his Ph.D. for original research in Supersonic Fluidics.

Dr. Thompson was Head of Research & Development in the Controls Division of Chandler Evans Incorporated, Connecticut, and was responsible for the development of new missile control concepts with both the U.S. Navy and Air Force. During his stay in the United States he undertook the duties of Visiting Professor at Rensselaer Polytechnic Institute.

He has published many papers and has been awarded the Simms Gold Medal for technical achievement and original research and holds several patents. As Director of the Marine Industries Centre, Dr. Thompson is on the Professorial Electorate of Newcastle University.

J. R. Tippetts

Born in Birmingham, England in 1943. He worked first with the English Electric Company and later obtained B.Sc.Eng. at Southampton University where he first became interested in fluidics. He then worked on fluidic flow control systems for nuclear applications in the department of Mechanical Engineering, University of Sheffield, and was awarded a Ph.D. in 1969. Subsequently, as a research fellow in the same department, he worked on electroviscous hydraulic power modulators. Since 1971 he has worked in the department of Chemical Engineering and Fuel Technology on gas turbine combustors and fluidic process-fluid handling systems for nuclear applications.

Roland Pierce Trask

A native of New Castle, Delaware, Mr. Trask graduated from the University of Delaware with a degree in mechanical engineering. In 1966 he joined the fluidic research branch of HDL.

Mr. Trask was appointed the Army representative to the Government Fluidics Coordinating Group and became chairman of the group's standardization committee.

As the Army's lead delegate to the International Standards Organization's "Working Group on Fluidics and Fluid Logic Systems," he coordinated the activities of the Society of Automotive Engineers and the National Standards Institute.

Roland Pierce Trask (cont.)

He played a major role in the use of fluidic technology to modernize many Army and Commercial plant operations. He received Outstanding Performance Awards in 1968 and 1973. He held four patents and nine patent disclosures in his field.

In 1969 he received a master's degree in mechanical engineering from Catholic University and was working on his doctorate there at the time of his death in January 1975.

A licensed professional engineer in Maryland, Pierce was a member of the American Society of Mechanical Engineers.

Tsutomu Wada

Tsutomu Wada was born in Gotsu, Japan, on April 21, 1929. He received the BE and Ph.D. degrees in applied physics from Kyoto University, Kyoto, Japan in 1953 and 1965, respectively. Since 1953, he has done research at Osaka city University, Osaka, Japan, and Okayama University, Okayama, Japan, respectively. At present, he is a Professor of Industrial and Mechanical engineering, Okayama University. His main interests are in hydrauric and penumatic control systems engineering.

Paul M. Wagner

Date of Birth: 14 May 1935

Title and Location of Present Position - Mechanical Engineer, Landing Gear Group, Mechanical Branch, Vehicle Equipment Division, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio

Education: B.S. Mechanical Engineering - University of Dayton - 1959

Current duties - Responsible for exploratory development efforts to meet current and future requirements in landing gear systems design. Efforts include fluidic brake antiskid control, novel tire concepts, new brake heat sink designs, and landing gear components and systems suitable for use on both conventiaonal and unprepared landing surfaces. Also, serves on advanced technical program planning groups and proposed aircraft design and evaluation teams.

Before appointment to the present position, held a position as an industrial engineer with the USAF Air Material Command (now Air Force Logistics Command) from June 1959 to March 1961 at Wright-Patterson AFB, Ohio. With AMC, performed studies to improve material handling techniques and optimize the utilization of existing facilities.

Membership: American Society of Mechanical Engineers

Colin J. Williams

Education: University College, Seansea, B.Sc. in Mech. Eng. in 1968
University of Windsor, M.A.Sc. in Mech. Eng. in 1970
University of Windsor, Ph.D. in Mech. Eng. in 1974

Robert L. Woods

Dr. Woods received his BSME degree (1967) from SMU. He received his Master's Degree (1970) and Ph.D. (1971) from Oklahoma State University specializing in Fluidics, Fluid Logic, and Controls. While at OSU, his major research was in Digital and Hybrid Logic Synthesis and Fluidic Control of Hydrostatic Transmission.

In 1971 he joined the Fluidics Staff at Harry Diamond Labs. Research topics at HDL include: high input impedance laminar proportional amplifiers, gas-to-liquid interface amplifier, optimum engine scheduling, aspirators, bridge gas concentration sensor, multiplier, high Reynolds number amplifier, fluidic circuits and systems. The major effort while at HDL was directed towards designing and building a fluidic fuel-injection system.

In September 1974, he joined the Mechanical Engineering faculty at the University of Texas at Arlington.

Dr. Woods is the author of numerous papers and several patents in the area of fluidics.

David N. Wormley

Dr. Wormley received the S.B. and S.M. degrees in Mechanical Engineering from M.I.T. in 1962 and 1964 and the Ph.D. degree in 1967. He is presently Associate Professor of Mechanical Engineering at M.I.T. where his teaching activities include automatic control, system dynamics, electromechanics, and fluid power control and fluidics.

Professor Wormley's research has included studies of the dynamic characteristics of gas thrust bearings, the static and dynamic characteristics of vortex triodes and transient and frequency modulated signal transmission in pneumatic lines and networks. His current research is directed to development of hydraulic multistage amplifiers and advanced vehicle suspension systems.

Professor Wormley is a member of ASME and Sigma Xi. He is the recipient of the Moody Award from the Fluids Engineering Division of ASME for technical papers describing design techniques for vortex triodes.

Robert Young

Presently Program Manager of Fluidic Technology at GE - Re-Entry and Environmental Systems Division. Responsible for the program administration of several fluidic contracts as well as company development programs.

Previously, he was a project engineer at Warwick Engineering with the responsibility for directing the engineering activities for designing and developing the automatic control systems for the company' line of finishing systems.

Prior to that his duties as a field engineer for Pitney Bowes was to establish a network of distributor outlets, train the distributor salesmen, attain given sales levels, supervise the installation of the company's equipment in customer plants and work directly with larger accounts.

Before that, his responsibilities as an engineer at Bendix Research Labs, included directing the activities of other engineers, draftsmen and technicians in the development of fluidic systems for commercial and military applications.

His original work assignment was with the Naval Air Development Center where he investigated the application of fluidic devices to control functions in naval aircraft.

ERRATA

Volume I

Vortex Diodes
S. S. Fineblum, Bell Labs, Whippany, New Jersey

pg. 48 - 5th paragraph

Add leading parenthesis between "inviscid" and "primarily" to obtain:

The purpose of the present work is to report a rational approach to inviscid (primarily incompressible) vortex diode design.

pg. 49 - equation (1)

Add Δ to "P" in denominator to obtain:

$$E = \left[\frac{\Delta P(\text{INVERSE})}{\Delta P(\text{FORWARD})}\right]_{\text{CONSTANT FLOW.}} \tag{1}$$

pg. 50 - equation (3)

Add equal sign after $\frac{\Delta P_I}{\Delta P_F}$ to obtain:

$$E = \frac{\Delta P_I}{\Delta P_F} = \frac{\left[\Delta P_e + \Delta P_N + \Delta P_{VC} + \Delta P_0 + \Delta P_t\right]_I}{\left[\Delta P_t + \Delta P_0 + \Delta P_{VC} + \Delta P_N + \Delta P_e\right]_F} \tag{3}$$

Figure 8

Omit "OR" in key in front of "RADIUS - 3"

The Turbulence Amplifier
A. Bell, State University of New York at Buffalo, Buffalo, New York

pg. 82 - 3rd paragraph, 4th line

'loose' should read 'lose'.

pg. 83 - 3rd paragraph, 10th line:

insert between 'but' and 'reduced' the word 'yields'.

pg. 83 - last line:

insert between 'load' and 'return' the word 'flow'.

The Turbulence Amplifier (cont.)

pg. 84 - line 8:

replace "the zero load" with "the maximum".

Analytical Design of Laminar Proportional Amplifiers

Francis M. Manion, Harry Diamond Laboratories, Washington, D.C.
Tadeusz M. Drzewiecki, Harry Diamond Laboratories, Washington, D.C.

pg. 162 - equation 4

radical should extend over ρ i.e. $\sqrt{2(P_s - P_v)/\rho}$

pg. 177 - equation 29

last term on left hand side of = should be divided by δ' and multiplied by P_j'. Next to last term should not have have radical extending over sgn $(P_j - P_v)$.

pg. 178 - equation 31

term $Y_j Z_c$ should be multiplied by 2.

pg. 181 - equation 41

last term should be divided by 2.

pg. 185 - equation 43a

should read

$$P_c/Q_c = R_v + R_c - (Q_{enet}/Q_c)R_v$$

pg. 187 - equation 46

terms in numerator and denominator $Y_j Z_c$ should be multiplied by 2.

pg. 213 - equation 73

first term on RHS should read "2.265".

pg. 226 - line 3

should read "... be off by 10 percent".

pg. 226 - line 8

should read "... 10 percent".

Experimental Design of Laminar Proportional Amplifiers
Richard F. Hellbaum, NASA-Langley, Langley, Virginia

pg. 238 - line 3

reads: ... The variable parameters were - - -

should read: ... The parametric values about which variations were made, one parameter at a time, were - - -

pg. 238 - line 19

reads: ... dyeing agent. The use - - -

should read: ... dyeing agent. This technique was contributed by Chris Spyropoulos of Harry Diamond Labs. The use - - -

pg. 248 - figure 4 Legend should read:

Figure 4. A plot of gain versus Reynolds number shows that the rapid increase of gain with N_R ceases for N_R greater than 800. $\sigma = 0.75$, $B_{sb} = 0.375$, $B_c = 3.25$, $L_r = 9.3$, $B_r = 1.0$, $B_{cv} = .75$.

pg. 249 - figure 5 Legend should read:

Figure 5. Higher bias levels yield reduced gain. Gain usually increases until an unstable condition exists but may reach a maximum and then decrease before going unstable. $B_{sb} = 0.375$, $B_c = 3.25$, $L_r = 9.3$, $B_r = 1.0$, $B_{cv} = 0.75$.

pg. 251 - figure 7 Legend should read:

Figure 7. Maneuvering distance b_m is the real clearance distance between the downstream edge of the control duct and a real supply stream.

pg. 252 - figure 8 Legend should read:

Figure 8. Gain is reduced as setback is increased $\sigma = 0.5$, $B_c = 3.25$, $L_r = 9.3$, $B_r = 1.0$, $B_{cv} = 0.75$.

pg. 253 - figure 9 Legend should read:

Figure 9. Input impedance to control bias flow (i.e., jet does not deflect) is increased as setback is increased, but impedance to control signal (i.e., jet deflects) is not changed substantially. $\sigma = 0.5$, $B_c = 3.25$, $L_r = 9.3$, $B_r = 1.0$, $B_{cv} = 0.75$.

Experimental Design of Laminar Proportional Amplifiers (cont.)

pages 258 and 259

The picture for figures 12 and 13 are interchanged.

pg. 260 - figure 14 Legend should read:

Figure 14. Increasing the control length tends to increase gain. $\sigma = 0.5$, $B_{sb} = 3.75$, $L_r = 9.3$, $B_r = 1.0$, $B_{cv} = 0.75$.

pg. 263 - figure 17 Legend should read:

Figure 17. Optimum gain occurs with receiver length around 9.3. $\sigma = 0.5$, $B_{sb} = 0.375$, $B_c = 3.25$, $B_r = 1.0$, $B_{cv} = 0.75$.

pg. 265 - figure 19 Legend should read:

Figure 19. Maximum gain is obtained from narrower receivers. $\sigma = 0.5$, $B_{sb} = 0.375$, $B_c = 3.25$, $L_r = 9.3$, $B_{cv} = 0.75$.

pg. 266 - figure 20 Legend should read:

Figure 20. Narrower center vent widths B_{cv} produce higher gains. $\sigma = 0.5$, $B_{sb} = 0.375$, $B_c = 3.25$, $L_r = 9.3$, $B_r = 1.0$.

The Effect of Geometric and Fluid Parameters on the Static Performance of Wall-Attachment Type Fluid Amplifiers
H. L. Moses, Virginia Polytechnic Institute and State University, Blacksburg, Virginia
R. A. Comparin, Newark College of Engineering

pg. 405 - σ Aspect ratio, h/b_s (not h/b_c)

pg. 411 - parentheses on equation 10

$$x_2 = \frac{d + \frac{b_s}{2}}{\cos(\alpha + \beta)} \left[\frac{\cos\alpha \cos\left(\frac{\theta + \alpha + \beta}{2}\right)}{\sin\left(\frac{\theta - \alpha - \beta}{2}\right)} + \sin\alpha \right]$$

pg. 429 - ordinate on Fig. 6 - Pressure, p/p_s

The Design of Flueric, Turbulent Wall-Attachment Flip-Flops
T. Drzewiecki, Harry Diamond Laboratories, Washington, D.C.

pg. 436 - line 19

should read "... roughly 0.145 psi, ..."

Effects of a Splitter and Vents on a Reattaching Jet and its Switching in Wall-Reattachment Fluidic Devices
T. Wada, M. Takagi, and T. Shimizu, Okayama University, Okayama, Japan

pg. 504 - equation (3) the expression

$$\cos(\alpha + \beta) - J_k \cos/J$$

which occurs in the denominator should read

$$\cos(\alpha + \beta) - J_d \cos\theta/J$$

Volume II

Downstream Control of a Jet
H. P. Lin, Stone and Webster Engineering Corp., Boston, Mass.
F. R. Swenson, University of Stirling, Scotland

pg. 32 - lines 7 - 9

control flow for switching to occur, (is) a measure of the device control sensitivity (and) for each control nozzle location and direction, is measured by ....

lines 14 - 17

.... differential pressure transducer with two sides connected to piezometric openings near the ends of the two side walls.

Volume III

Digital-Analog Hybrid Fluidic Feedback Systems
C. K. Taft, University of New Hampshire

Ordinate scale for Figure 3 should be

$$\frac{2a_o}{K} \quad \text{not} \quad \frac{a_o}{K}$$

Regenerative Process Fluid Switching Circuits
J. R. Tippetts, University of Sheffield, United Kingdom

pg. 100 - 6th line from bottom:

These can be allocated in 216 ways.

pg. 113

In these symbols for the gyrators, the arrow should be reversed so that it goes from right to left.

Signal Analysis of Fluidic Networks
H. Schaedel, Fachhochschule Koln, G rman Federal Republic

pg. 199 - equation (2.14)

$$P^{*}_{tot} = \bar{\rho} \cdot e$$

pg. 257 - equation (5.10)

$$\dot{m} = A_2 \sqrt{\frac{2p_2^*(p_1^* - p_2^*)/(R_g\ T)}{1 - (\frac{A_2}{A_1})^2}} = \frac{A_2\sqrt{2/(R_g\ T)}}{\sqrt{1 - (\frac{A_2}{A_1})^2}}\, p_2^* \sqrt{\frac{p_1^*}{p_2^*} - 1}$$

pg. 257 - equation (5.13)

$$\dot{m}_o = \frac{A_2\sqrt{2/(R_g\ T)}}{\sqrt{1 - (\frac{A_2}{A_1})^2}}\, p_2^* \sqrt{\frac{p_1^*}{p_2^*} - 1}$$

pg. 272 - equation (5.40)

$$\frac{p_2}{p_1} = \frac{1}{2}\ \frac{r_c}{r}\ \frac{1}{1 + j\omega\,\frac{rC}{2}}$$

Low Power Hydraulic Control Components
R. Deadwyler, Harry Diamond Labs, Washington, D.C.

pg. 462 - line 6

"capacitance" should read capacitive

pg. 462 - line 11

kP_a should read kPa

pg. 466 - equation 20

kP_a should read kPa

pg. 468 - line 14

kP_a should read kPa

pg. 469 - line 7

kP_a should read kPa

Low Power Hydraulic Control Components (cont.)

pg. 469 - line 42

kP_a should read kPa

pg. 469 - equation 26

should read $f_{lag} \doteq \frac{1}{2\pi(32.9 \times 10^{-?})} = 0.48$ Hz;

$$f_{lead} \doteq \frac{1}{2\pi(8.24 \times 10^{-?})} = 1.9 \text{ Hz}$$

Volume IV

Engineering Approximations for Fluidic Interconnections
H. L. Moses, Virginia Polytechnic Institute and State University, Blacksburg, Virginia
R. A. Comparin, Newark College of Engineering

pg. 239 - equation 8

10^{-3}sec (not 10^{3}sec)

Volume V

Flow Control Circuits for Toxic Fluids
J. R. Tippetts, University of Sheffield, United Kingdom
N. Syred, University of Sheffield, United Kingdom
J. Grant, Reactor Group. U.K.A.B.A., Risley, United Kingdom
R. E. Strong, Technical Services Department, British Nuclear Fuels, Windscale

pg. 382

The two equations in the 2nd and 3rd lines from the top should read:

$$q_c = (k/e_s)^{-\frac{1}{2}} F_c (E_c)$$

$$q_s = (k/e_s)^{-\frac{1}{2}} F_s (E_c)$$

pg. 393 - 1st paragraph, 8th line

..... characteristics are multi-valued in ......

pg. 385

Equations at bottom of page:

Q_x should be Q_s

Fluidic Emergency Roll Control
H. Haefner and T. S. Honda, General Electric Co., Schenectady, New York

pg. 500

The heading "Control System Concept" should read "VTOL Emergency Roll Control Requirements"

pg. 501

The heading "VTOL Emergency Roll Control Requirements" should read "Control System Concept".

D.SCUSSION

TECHNICAL SESSION I: Chairmen J. M. Kirshner, HDL and T. Wada, Okayama University

A Review of Vortex Diode and Triode Static and Dynamic Design Characteristics by D. Wormley, MIT

Question (J. R. Tippetts, Sheffield University):

Are you aware of the effects of chamber height variation in certain types of vortex amplifier? D. H. Saunders of the BHRA recently showed that diminishing the chamber height (to an unusual extent) could benefit the static characteristics significantly. If we take note of your observations on the response time, the small chamber height should also result in a faster dynamic response.

Also, I note that the dynamic response results are not in the proceedings. Are they available?

Answer (Wormley):

In answer to your first question, Yes. There has been a fair amount of work done and I tried to reference the work that I am familiar with in terms of both changing the chamber height and reducing the chamber height into a region in which it is smaller than the region in which it affects the static characteristics and it does a number of things. First, it quiets down the response considerably; for certain applications it can improve static performance from the point of view that it does quiet things down and it also gives a more proportional--like characteristic. In terms of turn-down ratio it will in some cases help and in some cases it won't help; it depends on what you mean by static response. The second thing is that there have been a number of studies of profiles in chambers which have also been done by that group as well as by Professor Bell and we have seen that they can also improve static response.

Now with respect to the dynamic characteristics, in the paper I have summarized the influence of the delay-time and the lag-time on the model. I have not included the actual experimental data. That is the subject of the paper that Wally Anderson is presently writing up and he requested that because that it was his doctoral thesis that he put that in at a little bit later date. However, we can certainly give you copies of the thesis.

Question (What are the purposes of this paper? Can you say something about phase shift?)

Answer (Wormley):

The first purpose of the paper was to review the work that has been done in vortex amplifiers over the past few years and I hope that we have covered most of the significant work that has been done in that area. As far as the dynamic work is concerned, some of that was also review and relied heavily on Lael Taplin's work but there was some new material in

there that as far as I know is the most up-to-date material available in that area. With respect to the phase shift we did show that the phase shift can be significant and the answer to that question is that now that we do have an analysis that can be used to predict what this phase shift is, we can begin to design amplifiers so that they will operate in the region in which the phase shift is not significant so that we have an amplifier with a good enough dynamic response to meet the particular applications demands that are at hand. Before this, we couldn't really predict in detail. We could get a rough estimate but not predict in detail over the complete operating characteristics what the phase shifts would be.

The Turbulence Amplifier by A. Bell, State University of New York at Buffalo

Question (J. D. Malcolm, Memorial University):

I wanted to ask you, if in your opinion one of the major problems in applying the TA is the fact that the delay time in switch-off is considerably different from delay-time in switch-on and is there any hope in designing a shroud or some other control geometry which will allow these two delay times to become reasonably similar. Is this a problem or not?

Answer (Bell):

I think that it is a major problem. In a number of circuit applications it is necessary to have one amplifier go off at the same time as another one comes on; the flip-flop is a perfect example of that and a number of other more complicated systems have the same problem. The point that he is making now is that the delay-time between turning one off or the total time it takes to get off is very different from the total time it takes to get on. There has been some research done in improving that situation. There were a number of papers that reported, (at the Fourth Cranfield Conference and the Fifth Cranfield Conference I believe) the in-building of edges and so on into the jet cavity. These were supposed to bring the times closer together. To my knowledge no one has actually built turbulence amplifiers in which the delay time on and off were the same.

Question (Malcolm):

Is it a problem?

Answer (Bell):

It depends on how fast you want to do things. One of the major problems with turbulence amplifiers is that they are slow in general. So if you are pushing, if you're trying to do things fast, trying to overcome the fact that it is basically a slow element then you get into problems sometimes. If you are not, if you're counting milk cartons as they go by, then it is no problem at all.

Question (T. M. Drzewiecki, HDL):

I have a comment on the fluidic mechanics of the measurement of the jet profile in which you mentioned the notch in the velocity profile. I would like to suggest some of the measurements that Andrade took on laminar jets back in the 30's and he didn't find this notch and I also recommend some of the work done by Brighton and also Pai and Weske at the University of Maryland where they found this effect to be due to the entrainment of the jet down stream and since you have an open configuration you're drawing flow in from behind the emitter---

Answer (Bell):

That is what I said; that notch was basically due to the emitter and in fact you can influence the notch very strongly by changing the geometry of the emitter nozzle.

Question (Drzewiecki):

No, I am not saying that. I am saying that the fact that you have no wall in back of the emitter and you are allowing flow to be entrained from upstream of the emitter along the side of the emitter. Essentially you have coaxial flow, an outer stream and an inner stream and this has been shown by Brighton and also Pai and Weske.

Answer (Bell):

I think we agree. The point that I made was that it was due to this entrained flow.

Question (Drzewiecki):

The thing is that you wouldn't have it if you had a shroud with the flow being blocked off from the back.

Answer (Bell):

You wouldn't have it if you had a shroud with the flow being blocked off from the back if the end of the emitter did not stick very far out of the shroud. In most turbulence amplifier geometry the end of the emitter does stick out of the shroud usually as much as six or eight or ten diameters in some people's configurations; as much as ten diameters will get that effect. It has to get down to about one-half a diameter before you don't get that effect.

Question

I am, surprised at the circular symmetry of this thing as shown so I wonder if the measurement of the profile was made from all around or several cross-sections or was one-half of it observed at one section and the figure drawn all around.

Answer (Bell):

I would answer that by saying that we measured those velocity profiles by transversing the entire jet both horizontally and vertically and that the ring appears, that is, that bump that you just referred to appears to be entirely symmetrical. And it is true that when one looks at the turbulence intensity fluctuations in a jet of that sort that they are highest at the bump and that when the jet begins to become fully turbulent it begins at the bump.

Question (E. Markland, University College):

Did I see on some of the results an abscissa marked "modified Reynolds number (R_e/L)" and if so, is that quantity dimensionless?

Answer (Bell):

Yes. Because L is. L is defined as the length of the emitter divided by its diameter. In the text that is made clear.

Question (H. Schaedel, University of Cologne):

May I perhaps give a comment to the question of the turn-on and turn-off time. As far as I know Mr. Glaettli from Switzerland has made an extensive investigation on this subject and he found that the turn-off and the turn-on time depend on the shape of the shroud and that you can make the turn-off time longer than the turn-on time and just the reverse. Perhaps you can contact Mr. Glaettli about this if you are interested. I can give you the address of Mr. Glaettli. Perhaps I can ask one question of you about the sound sensitivity of the laminar jet. Is this the sensitivity of the free jet or the sensitivity of an enclosed jet with a shroud because I think that the shroud will influence the whole characteristics of these resonant frequencies or sensitivity frequencies?

Answer (Bell):

The shroud will definitely influence them because the shroud cavity dynamics then very definitely enter into the picture. So to say that the frequency data given there is in any way useful for an enclosed jet is not intended at all.

One other point I might add is that Hayes has done a series of experiments in air that show that shroud diameter has very little effect on switch-off times but very significant effects on switch-on times so that clearly one can modify things by playing around with shroud diameters. But one of the difficulties there was that it appeared to me that in decreasing shroud size or for various short gaps that were used in some of these experiments one was sacrificing static performance for the dynamic performance.

Experimental Design of Laminar Proportional Amplifiers by R. F. Hellbaum, NASA/Langley

Question (Schaedel):

Could you say some thing about some of the advantages the laminar proportional amplifiers you developed have compared with the usual proportional amplifiers.

Answer (Hellbaum):

You are asking what are the advantages of having a laminar amplifier over a turbulent proportional amplifier?

Question (Schaedel):

Yes. And the possibilities of application that you were looking for.

Answer (Hellbaum):

The particular application which I had in mind, if I may answer that one first, was for a wing leveler for light aircraft, i.e., for the man who flies a single engine, two or four seater. Usually he can't afford $10,000 for an autopilot and we were looking for something that might be in his price range which would let him let go of the stick and get a cup of coffee and look at the map and find out where he is, this type of thing. It has the potential for getting him out of trouble if he loses orientation, for example, in a storm. That is the application that I had in mind. In general when you have an application which requires looking at minute signals where you need a lot of gain and a high dynamic range, for example, that's when you are looking for laminar devices for that very reason, they have high dynamic range and they're quiet.

By the way I should point out that Ted, Frank and George have worked on these quite a bit. I have received quite a bit of help from them.

Comment (T. Drzewiecki, HDL):

I would like to point out the low power consumption of a typical stage of one of these devices. We're talking in the range between one-tenth to ten milliwatts per stage for a device with a 20 thousandths of an inch supply nozzle. That is about an order of magnitude less than is now commercially available.

Question (J. Woodroffe, Avco Research Labs):

You mentioned that your operating point is a Reynolds number of 500. I would like to know what your ideal operating point would be if you didn't have to worry about the turbulent onset.

Answer (Hellbaum):

If you didn't have to worry about the turbulent onset? Frank Manion will be covering that in the next talk.

Question

When you use a Reynolds number even as low as 500, I did notice that the jet always contains some turbulence or noise. Did you, during a continuous switching process, examine the noise and signal ratio in this amplifier?

Answer (G. Mon, HDL):

I think I can answer that question. We have hooked up the laminar proportional amplifier as an oscillator operating in a frequency range of 200-300 Hz and have looked at the waveform on an oscilloscope. Even with great amplification of the waveform on the scope we didn't see any fluctuation due to noise.

Question

How much noise is there?

Answer (Mon):

We couldn't pick it up with our transducer which can sense a pressure as low as 10^{-4} psi. The noise is very much below the amplitude of the oscillating signal. The dynamic range is greater than 1000.

Analytical Design of Laminar Proportional Amplifiers by F. Manion and T. Drzewiecki, HDL

Question

The output data that you have shown without any noise on it. To what Reynolds number used by Hellbaum does it correspond?

Answer (Manion):

The Reynolds numbers of both were about the same. Ours may have been slightly higher than Hellbaum's. Remember that his supply pressure was extremely low and very sensitive to vibrations. This is why we want the amplifier to have good common mode rejection so that those signals coming into both control channels do not give us an output.

Question

I saw turbulence on the amplifier power jet on Hellbaum's flow visualization figures.

Answer (Manion):

That noise is not within the bandwidth of the amplifier. Lets qualify that. Are you talking about Mr. Hellbaum's large liquid amplifier with a supply pressure head of 70 mils of water or are you talking about an amplifier that has a 2 psi supply?

Question

Either one.

Answer (Manion):

The amplifiers are not that sensitive because Mr. Hellbaum has taken amplifiers working on air down to 1 millimeter of water supply and has gone through environmental tests including vibrations, without running into problems. The thing you have to remember is that we have a boundary layer in the top and bottom planes that tends to stabilize the jet. A two dimensional jet would be well turbulent, but the presence of the top and bottom boundary layers extends the Reynolds number for laminar flow quite a bit when compared to two dimensional jet flows.

Question

Did you take that into account in your analysis?

Answer (Manion):

The analysis used a two dimensional approach with the three dimensional effects accounted for to some extent (at least as far as the nozzle was concerned) in the discharge coefficient. This still gives good results which are within ten percent.

Comment (Hellbaum):

On this whole question of noise. When you saw something that appeared to be turbulent, remember that I had a big tank with tubes of water hanging down. If you touch that anywhere, it is going to shake things. In my autopilot I have to make sure that all tubing is rigidly secured so that signals aren't generated due to vibrations of the tubing. The amplifier itself is pretty well insensitive to vibration itself, but if you generate a signal elsewhere due to vibration and put that signal in, it is going to amplify it.

Comment (Manion):

Actually that depends on the Reynolds number. At the lower Reynolds number you get a lot of supression of disturbances and the higher the Reynolds number the more gain and less supression.

Question (Dr. R. Bowles):

To give an envelope on the fastest dynamic response you could expect from amplifiers of your type, suppose you have only a limit of 5 mils on nozzle size and that you can pick your fluid and pressure and everything. What sort of ball park would you say for an upper frequency response?

Answer (Manion):

Well how do you want to define the frequency response — where the phase lag is 45 degrees? Because these are combinations of a second order input system and you have the output system and the receiver plus the transport delay so do you want to qualify it with 45 degrees lag?

Question (Bowles):

No. All I am looking at is gain rather than phase lag. I am looking for something for the man who doesn't know all of the details of the design and he wants to whether or not he should look at your design in order to attack a problem and he just wants to know a ball park number of how fast might he hope to make this if he has no restrictions on the supply fluid.

Answer (Manion):

I don't want to give a misleading answer. In addition to the amplifier itself, you have to be careful about channels. What limits these devices is that you can't neglect the impedance characteristics of the channels and this is going to dominate the characteristics of the device as a whole. So just telling you what we can do in one element doesn't mean that we can retain this bandwidth from one element to the next. I am consequently reluctant to give you a number that is based on just a Reynolds number and the size of the unit.

Question (Bowles):

Well, can one look at a system only up to 50 cycles per second or can he look at a systems of 500 or 5000.

Answer (Manion):

You can look at a system from 500 to 1000 with reasonable size devices.

Question (Bowles):

What if he has to push it?

Answer (Manion):

He would then have to be very careful about the connecting lines.

Question (Bowles):

If he has to push the system, can he go to 10,000.

Answer (Manion):

I doubt it.

Question (Bowles):

That's the sort of answer I was looking for. Thank you.

Jet Deflection Proportional Amplifier by A. Healey, University of Texas at Austin

Question (Drzewiecki):

What did you use to model the resistance of the output lines and the center dump in order to match the impedance of the jet to it?

Answer (Healey):

For the steady state pressure recovery this was an orifice load and steady state friction in the passage.

Question (Shearer):

In other words you included the length of the lines.

Answer (Healey):

Yes.

Question (Schaedel):

You investigated the influences on pressure and flow recovery in one single amplifier in one stage. Do you think that you can get information for staging two amplifiers for optimizing a two stage amplifier because then you have to look at the signal energy transfer. Do you think it is possible?

Answer (Healey):

One needs to know the input characteristics for the device and that was not discussed here. With the model for the input characteristics of a similar device then you could go through the staging process.

Question (Schaedel):

But it could be sensible to measure the deflection of the jet of the second amplifier and then to look not so much at the pressure and flow recovery but that you optimize the deflection of the second jet.

Answer (Healey):

This is something that certainly can be done. It wasn't the aim of the work at the time.

Fluidic Proportional Amplifiers for Very Low Reynolds Number by R. H. Bellman, Corning Glass Works

Question

What are your conclusions?

Answer (Bellman):

What are my conclusions? The main problem in making a device to run at very low Reynolds numbers is that you have viscous losses in the nozzle. You can reduce the viscous losses by changing the power nozzle shape. There is a limit to what we at Corning can do in two dimensions. Three dimensional nozzles reduce the losses even further. If you look at the fourth curve where we talked about Reynolds numbers you could see that I could have made a great big device and solved the whole thing right away without doing anything. That wasn't economically feasible; in fact the whole project that I worked on here is right now sort of in the air because the pricing is still too high. We have to come down on pricing yet. It is not in the fluidic part of it but in the diaphragms and junk that goes with it.

Comment (Drzewiecki):

I didn't know that Mr. Bellman was working in this particular area. It points out though the importance of the discharge coefficient in the design of an amplifier and the real necessity of being able to design an efficient nozzle for some applications. There are applications, however, where one might want to have a low discharge coefficient nozzle because if one considers the decrement to momentum flux coming out of a nozzle like this it goes approximately as the square root of the discharge coefficient. If you had a discharge coefficient of around .7 you would be talking about momentum flux of less than about a half of the momentum flux of an inviscid jet. However, as you decrease momentum flux out of the nozzle it's just that much easier to deflect the jet. For some particular applications where you need a soft jet you may actually want to have a poor, momentum loss, type of nozzle.

I would like to point out also that the equation that Frank showed before on the losses due to surface shear of the jet actually become very critical at the very low Reynolds numbers we're talking about (let's say for an aspect ratio of 1) a Reynolds number of less than about 500 based on nozzle width. We are talking about the predominant losses being in the space between the jet exit nozzle to the receiver where the loss is actually maybe around 60 or 70 percent of what is coming out of the nozzle. So obviously if you have only 50 percent coming out of the nozzle to begin with and you decrement that another 75 percent you get very low pressure recovery and low gain.

I would like to thank Mr. Bellman on the independent check of our data.

Question:

I would like to ask of all those who talked about the laminar devices as to what they jointly conclude as far as fluidics and its applications are concerned. What does the future hold?

Answer (Manion):

I'll try to answer that as far as we are concerned. We have been looking at control systems and we looked at a lot of amplifiers before we started to look at the laminar flow regime. The big question is that in control applications you cannot work with dynamic ranges that are 100 or 200 or even less which is what you encounter in turbulent flow. There is really no way to increase the dynamic range of the turbulent devices that we could think of, it is a tremendous problem to try to keep a jet from going into transition, and we are not going to solve that problem. By going into the laminar flow regime we have measured dynamic ranges of up to 10,000. The signals obtained are so clean that people don't believe they are fluidic. The ability to see extremely small signals allows you to build preamplifiers because it allows you to pick-up sensed signals without losing their integrity. I think it is important from the point of view that it will take a small sensor signal and bring it up to working level, then you can use power devices for actuation, but if we can't process a small signal, fluidics can't get into the control field, so I think that is where the important impact is.

TECHNICAL SESSION 2 - Chairmen: Forbes T. Brown, Lehigh University and G. A. Parker, University of Surrey

The Effect of Geometric and Fluid Parameters on the Static Performance of Wall-Attachment Type Fluid Amplifiers by H. L. Moses, Virginia Polytechnic Institute and State University and R. A. Comparin, Newark College of Engineering

Question (F. T. Brown):

You use the Goertler profile for the shape of the jet in this paper. Does this mean that you recommend the use of this profile over profiles which allow for a development length?

Answer (Hal Moses):

No. I pointed out in the paper that the equations are for the most part not recommended procedures; just examples. I used the Goertler profile simply because it is the best known. Other profiles at least for the fully developed region would work just as well. We should include the development length also; the problem is that for most devices there is some distance where the jet is not turbulent; that distance is usually about three or four nozzle widths, and any analysis that assumes the jet is fully developed or turbulent is likely to be very approximate. It is my opinion that this is the reason why we have to vary the spread parameter.

Question (Schaedel):

Could you give some information of how closely the static input and output characteristics can be determined.

Answer (Moses):

The input characteristic can be predicted quite well simply because it is a nozzle characteristic. Most devices are vented so that the static pressure at the exit is very close to atmospheric and we can predict the input characteristic very well in that case. The output characteristics are much more approximate, but depending on the particular device, we can predict some of these reasonably well. I must say, though that we can predict trends better than we can predict actual performance.

Question (Schaedel):

Is there information in your paper about this because you didn't mention it?

Answer (Moses):

Very little, I referred to a couple of papers, one by myself and Comparin, one by Sarpkaya, and one by Drzewiecki and Goto. There are three examples where some calculation are attempted.

Question (Unintelligible)

Answer (Moses):

This is a review paper. Its purpose is to present basic ideas and key the reader to the literature. Most of the work that I am describing here has been published although some of the experiments were not published. I did not manage to find a great deal of data where parameters were systematically varied one at a time.

Question

What do you see as the future direction in wall-attachment devices?

Answer (Moses):

That is difficult to answer. It is a value judgement, and there is some question as to whether simply making a better flip-flop would improve the fluidics picture. But I share with you I think the idea that basic research is worthwhile even without some definite objective like making a better flip-flop. I would say simply from a fluid mechanics point of view, not from a commercial point of view that perhaps the flow in the receiver area, particularly with a wide or cusp splitter would be most promising area, and I am not yet satisified with the attachment models, particularly for low offset.

The Design of Flueric Turbulent Wall-Attachment Flip-Flops by T. Drzewiecki, HDL

Question (Unintelligible)

Answer (Drzewiecki):

As far as the prognosis for turbulent devices or for turbulent wall-attachment devices I would like to say that presently the work at the Harry Diamond Laboratories is solely limited to laminar (research in laminar devices) and as such we are not really working in this area. However, we can be of any help to anybody else working in the field we certainly like to do so.

Question (R. Warren):

Did you try the rounded nozzles on the contacting opposite wall type switching? We found that when we rounded the nozzle that the velocity of the stream decreased, the pressure went up but the stream (the power jet) did not contact the opposite wall as quickly. So this is the reason that that control was kept as close to the power jet as possible.

Answer (Drzewiecki):

Yes. I think you are referring to the latching vortex devices. I believe that the empirical trade-offs in a latching vortex device are slightly different than for a sharp splitter.

Question (Warren):

In splitter switching you are not really interested in the velocity of the control jet, but in wall switching where it contacts the opposite wall prior to passing the splitter you are interested in the velocity of the control stream. So that rounded control you have there, we found, greatly decreased the velocity with which the control stream hit the power jet and slowed down the switching whereas the other case speeded it up.

Answer (Drzewiecki):

When we are talking about a low off-set wall-attachment device where the gain is very high, for example, on the order of ten or twenty and where we are talking about control signals which are less than one-tenth of the supply jet pressure, the action of the momentum of the stream is very small on the jet. Essentially the entire pheonomenon is in the filling of the bubble. No matter what kind of device you have or what kind of switch you have, you must always fill the bubble and you must always pierce the bubble. You will not have switching if you have a bubble on that side. There are only three ways that a bubble can be pierced or broken, 1) If it passes the end of the attachment-wall, 2) If it hits the splitter before it hits the vent (we have been labeling that as splitter switching), and 3) If the attachment angle gets to be greater than roughly sixty seven degrees and you start getting more flow into the bubble from the jet than is required by the entrainment causing natural instability. In the last case the bubble grows, but the bubble still must burst, the jet still must pass the vent and it still must pass the splitter; however, once it has gotten to this unstable point it will continue on no matter where you have the vents or the splitter.

Question (Warren):

Once you touch the opposite wall you have a completely new ball game.

Answer (Drzewiecki):

Exactly, what happens is that you squash the bubble. The bubble cannot expand any more against the wall so the only other way it has to go is downstream. By providing this corner on the edge of the wall you are providing a low impedance to the bubble and allowing more flow to go into the bubble more quickly. Agreed, the bubble pressure will rise as you hit the opposite wall but you are still allowing more flow to get in more quickly. I think that if you look at the paper it will become fairly obvious.

Question (Warren):

I agree with you on splitter switching but the minute you have the jet on both walls you have an entirely different set of conditions than when it is on only one wall and it has the characteristic that the feedback along the far side of the stream is greatly reduced so that the jet attachment point tends to run down the far wall and you switch at a much lower flow into the bubble.

Answer (Drzewiecki):

Yes, that is exactly true. I think the problem is that the model that is presented here doesn't differentiate between any three particular stages, but it does include the effect of the opposite wall.

Question (Warren):

Have you included momentum in your model? In the very close wall device if there is more momentum in your control jet it contacts the other wall easier; switching is a combination of mass flow and momentum effects.

Answer (Drzewiecki):

Yes, momentum is included, however at the supply pressures that we're talking about and for the threshold switching of one of these devices where the control pressure required is less than one tenth of the supply pressure, the momentum involved is about one one-hundredth of the momentum in the supply jet and therefore the contribution of the momentum is far outweighed by the contribution of the pressure field on that jet.

Question (Schaedel):

I would like to refer to your figures 18a and b on page 490. There is a lot of ringing on your lines at the output of the amplifier. Is there any reason why you didn't try to match the lines so that you avoid the ringing.

Answer (Drzewiecki):

There was no effort at all at this particular time to match the outputs; if you appropriately design the output, ringing can be completely removed; however, it is a very interesting point that the rise time is increased considerably and you lose frequency response. If you can tolerate ringing than you would actually want the outlets to be underdamped so that you get the maximum rise time.

Question (Ernest Taylor, Monsanto Textiles):

I see that in your article you use both the terms fluidic and flueric and I am not familiar with the distinction between the terms, if you don't mind I would appreciate an explanation.

Answer (Drzewiecki):

The official military terminology for no moving part fluidics is fluerics and fluidics is the generic term for any kind of hydraulic/pneumatic control, computation, sensing, or logic devices so that diaphragm logic, even perhaps flow valves might be considered fluidics whereas wall-attachment devices and proportional amplifiers that have no moving parts are considered flueric. For those of you who are interested, out in the lobby there are copies of Mil-Standards 1306 and 1361 which explain the official terminology.

Question (Taylor):

Might I ask this then, is there a pressure distinction between fluidic devices and moving parts logic? I heard both terms used.

Answer (Drzewiecki):

No, not according to the way fluidics is defined. As I think was mentioned before by Dr. Moses there are turbulent flip-flops or logic devices that operate in the supersonic regime. In many logic devices, on the other hand it is important to use as little pressure and as little power as possible.

Effects of a Splitter and Vents on a Reattaching Jet and Its Switching in Wall Reattachment Fluidic Devices by T. Wada, M. Takagi, and T. Shimizu, Okayama University, Japan

Question (Drzewiecki):

I would just really like to ask how long and how many people did it take to take all this enormous mass of data. I read the paper and I looked at all the data involved, I could see that it must have taken many years to take all this data. Could you please tell us how long it took and just how many people worked on this or was it just the three people and the author?

Answer (Wada):

It took three people (the authors) about seven years to take all the data.

Question (Dave Keyser, Naval Ship Engineering Center):

The illustrations (photographs) with the flow patterns — are those water with metal chips or is that air with smoke, I didn't get a chance to read the paper ahead of time?

Answer (Wada):

The flow visualization in the water model was done by polystyrene grain tracers.

The Laminar Flip-Flop by T. Drzewiecki and F. Manion, HDL

Question (Dr. Shearer, Penn State University):

On the business of dynamic response I can see where you have the desire to work with the natural frequency of the laminar proportional amplifier to get some idea of what the switching time might be and I think this is probably a good starting point to get a figure of merit, but what do you estimate the switching time to be in terms of let's say the period of this natural frequency let's say it is a 100 Hz natural

frequency. How many times one of those periods is the switching time? That is, what is the period of one complete cycle at that natural frequency compared to the switching time. Is it two or three of those periods?

Answer (Manion):

It really depends on the design details, Dr. Shearer, on how close the edges are and how negative the bias vent pressure is. I think it is around two or three.

Projects on Moving Part Fluidic Devices Carried Out at Sir George Williams University by C. C. K. Kwok, Sir George Williams University, Canada

E. Markland presented this paper.

Comment (S. Fineblum, Bell Laboratories):

There is a very practical application that is even more dramatic than the one shown. If you want to put out an electrical fire with water, a safe way to do it,(because water is conductive) is by slugs of water in oscillating streams. Thus, you can achieve the mass flow from the pressurized fire extinguishers to the fire but you don't have an electrical current path to endanger the fire fighter. This is an application that is being worked on by W. B. Eaves of our division.

TECHNICAL SESSION 3: Chairmen J. L. Shearer, Pennsylvania State University and R. Bowles, Consultant

A Survey of Sensors, Parts I and II by A. Schmidlin, Picatinny Arsenal and J. M. Kirshner, HDL

Question (Karl Reid, Oklahoma State University):

Did you mention flow sensors?

Answer (Schmidlin):

No. I did not cover flow sensor in my talk, they <u>are</u> mentioned in part II of the paper.

Question (P. Zalesky, Air Force School of Aerospace Medicine):

I wonder if you could suggest a scheme for isolating the effec of CO_2, O_2, and temperature that are changing simultaneously.

Answer (Schmidlin):

Well I think you raised a difficult question. You can eliminate temperature effects by using a reference gas and processing both the reference and the unknown gases in a heat exchanger so that they are

both at the same temperature Off hand I don't know how you would account for CO_2 and O_2 changing simultaneously. (Suggestion volunteered from the audience to selectively remove the CO_2 (or O_2) with an adsorbent).

The Fluidic Acoustic Sensor by B. B. Beeken, Automatic Switch Comany

Question (G. Roffman, HDL):

How does your device compare in let's say cost and performance to the conventional photo cell?

Answer (Beeken):

Our cost depends on the system. There are so many different photocell systems and so many different applications it depends on the environment and the demands on it. We find that our costs are comparable to many photo cell systems compared to which we have advantages. You know that in dusty atmospheres and in oily atmospheres the lenses of photocells get coated and just start malfunctioning. Thats where we come in because we don't have that problem at all. It can be the dirtiest atmosphere you can think of; we have systems in rolling mill situations where they're looking at hot ingots. There is a temperature gradient problem, but they realized that they had to look through the gradient perpendicularly, and it works beautifully even though they couldn't get photo cell systems to work for any time in that environment. There is steam and you name it in there.

Question (D. Hellbaum, NASA/Langley):

It looked to me from the one graph that it was operating around something like 5 watts of power.

Comment (Beeken):

Five watts! I don't think it is that high. I believe it is about one watt, but I don't remember off hand.

Question (Hellbaum):

You said something about monitoring passengers in buses, I was wondering about this. Isn't this in the audible range?

Answer (Beeken):

No, it is not in the audible range. 50 kHz is well beyond the audible range.

Question (Hellbaum):

Oh you said fifty kc! Does it make any audible noise.

Answer (Beeken):

You can hear a faint hiss which is due to the exhaust but you can't really hear that when it is all enclosed.

Question (Vondell Carter, HDL):

I don't believe I heard you mention a response rate for the switch.

Answer (Beeken):

The response time is in the order from 1-2 milliseconds.

Question (Andy Marshall, Sperry-Vickers):

Have you in your applications had any problems with interference noise? I noticed your distances were 18 ft.

Answer (Beeken):

Not yet. The sensor is at 50 kHz ±3 kHz. Now, obviously somewhere along the line leaking air or a machine noise is going to produce that. But in order to interfere it must be of sufficient intensity. If it let's say coming from a leak somewhere, the wave is spherical and by the time it gets any distance it has dropped off considerably. It would have to be right up against the sensor to interfere. We have tried all kinds of things to create disturbances but we just can't knock out the signal.

Question (Shearer):

That power level you gave. Did that include the whistle?

Answer (Beeken):

Yes, it included the whistle.

Theoretical Analysis of a Two-Dimensional Laminar Jet Rate Sensor by Dr. Paul Jacobs, US Army Missile Command, Redstone Arsenal, Huntsville

and

Development of a Laminar Angular Rate Sensor (LARS) by R. Young, General Electric Company, Philadelphia, Pa.

Question (Ray Thompson):

Unaccustomed as I am to giving praise, I would like to take this opportunity of congratulating Mr. Young on an excellent presentation, particularly in view of the substantial content involved in the paper. In view of the fact that Mr. Young mentioned temperature compensation

perhaps he would be kind enough to detail the mode of operation. Furthermore, it is to be noticed that there is a small orifice upstream of the main discharge orifice, the function of which could bear some explanation.

Answer (Young):

We have an orifice and a laminar resistor such that over a temperature band the effect of the temperature on the orifice flow characteristic and on the laminar resistor are such that the effects tend to cancel out. In addition what we have done is to use a preheat wire in the inlet flow stream since we are not worried about the temperature of the body of the actual metal but of the inlet air because the air is controlling the performance.

Question:

Don't you have a problem with external noise in the vents?

Answer (Young):

We have had several people discuss the problem of external influences on laminar jets and we have designed a shroud that decouples the vent cavity from the external disturbances. One way that this is being done is to raise the pressure so that the flow is sonic and have a sonic exit nozzle in the vent chamber to decouple any and all downstream loading.

We designed decoupling cavities shrouds and we ran vibration tests, hammering (shock) up to 110 dB acoustic noise at 0 to 5000 Hz and found absolutely no effect on the rate sensor. But it is not in the basic rate sensor that we do the decoupling. It is an external shroud that has to be incorporated properly designed to adequately attenuate the external acoustic energy.

Mathematical Modeling and Computer Aided Design of a Fluidic G Sensor by Charles A. Belsterling, Franklin Institute and A. E. Schmidlin, Picatinny Arsenal

Question (Ray Thompson):

The results of the authors underline the normal limitations of utilizing a digital machine for real time modelling. Furthermore, in the area utilizing the analogue machine difficulties occur with respect to the presentation of non-linearities by the use of function generators. I would like to suggest that this could be resolved by the utilization of a full hybrid facility and I would like to know if the authors have considered such a machine. A disturbing technical point is that gains of the value of 10^4 are shown in some of the analogue loops. Is this an error or, if not, has the question of stability been analysed?

Belsterling:

In the analog computer program?

Thompson:

In the analog computer program which showed, I think, a gain of 10^4 before it went into an integrator. This leads to quite a lot of errors, of course. What I was going to come down to the pitch of my problem or my question is have you considered hybrid computation as opposed to using purely digital or purely analog because obviously you can use the advantages of both pieces of equipment?

Belsterling:

Yes. Hybrid computation, of course, has a lot of advantages. You can, as you say, do your computation in real time sometimes or in an advanced time scale which is convenient to an analog simulation. The important thing is that you can store all kinds of nonlinearities in the digital portion of the hybrid simulation but you may have a problem with real time. You have to draw out that information from the digital portion of the hybrid simulation at sometimes high rates. In that case you can have some limitations. But we feel that hybrid is one of the best ways to go because you can slow down the analog simulation enough to be compatible with a reasonable speed of digital computation.

Thompson:

The transfer of data within modern hybrid machines is extremely rapid, the average digital machine having a sweep frequency of some 30 kHz. It has been our experience that even in the analysis of shock wave detonation effects applied to ship's hulls due to the dropping of depth charges we can still obtain the required speed of response on the digital machine together with maintaining the advantages of undertaking integration on the analogue facility. Certainly, it is my opinion that the controversy regarding digital v. analogue can be resolved simply by purchasing a hybrid.

A Fluid Amplifier Reynolds Number by T. Drzewiecki, HDL

Question (Malcolm, Memorial University, Canada):

All these curves are for turbulent flow. Right?

Answer (Drzewiecki):

No. The last statement was that we found out that there was a unique value for the establishment of fully turbulent flow.

Question (Malcolm):

You are probably anticipating the question but it is clear now from the program of this symposium that the advances are being made in laminar submerged jet devices and is there some correlation which are empirical fits on your curves for the laminar case?

Answer (Drzewiecki):

I guess I will handle the last question first. First of all they're not empirical fits. It's all theoretically calculated and it is all for laminar flow. The entire theory for calculated discharge coefficients is based on laminar boundary layer flow. The apparent reason for this unique value of modified Reynolds number appears to be correlated to the fact that at that value of Reynolds number you are discribing a net velocity profile (a laminar velocity profile) at the exit of the supply nozzle which will then immediately turn turbulent. As you can appreciate, as the Reynolds number becomes lower, there is some length of laminar flow in this device and then it is turbulent downstream. Apparently this value of Reynolds number predicts a point at which flow becomes turbulent right past the exit but the flow within the nozzle is still all laminar.

TECHNICAL SESSION 4: Chairmen K. Reid, Oklahoma State University and R. Thompson, University of Newcastle Upon Tyne, United Kingdom

Digital Fluidic Component and System Design by G. A. Parker, University of Surrey, United Kingdom

Question (R. Thompson):

I would like to ask Dr. Parker a question. He has the advantage over most of us in that he's done a study in depth of the components and technology which is presently available to the fluidic engineer. Can he perhaps let us know whether or not he feels that the general trend of fluidic design (I am talking about components as opposed to systems) is towards moving part devices rather than non-moving part devices. The author mentioned activities occurring in this field in the USSR and obviously there are developments being undertaken here in the USA involving moving parts. Perhaps the author would care to provide us with the benefits of his experience.

The number of scans is S_n since the last scan value is always stored.

$$\text{mean} = \left(\sum_{i=1}^{n} X_i W_i\right)/S_n$$

$$\text{standard deviation} = \sqrt{\frac{S_n \sum_{i=1}^{n} (W_i X_i)^2 - \left(\sum_{i=1}^{n} W_i X_i\right)^2}{S_n (S_n - 1)}}$$

The median value is that data value where there are as many data values (considering the weight factor) less than its value as there are greater than its value.

Also included in the system table are the minimum and maximum values for all the common blocks that the user has defined and used (section 6.3).

One additional feature in the table is the status of either a card punch (section 4.3) or tape write (section 4.4) for the identifiers in this file. This is indicated by putting a Y (for yes) or N (for no) under the PUNCH/TAPE/PLOT column for each option.

Another feature in the table is the status of a punch or tape output for the PLOT command (section 6.1). This is indicated by putting an N (for none), C (for card output), T (for tape output) or B (for both card and tape) under PLOT in the PUNCH/TAPE/PLOT column for each identifier.

Immediately preceding the above table output is the following information, where j is the number of scans in the file, k is a tape drive logical unit number, t is the tape length at start of the tape write, m is the tape length at the end of the tape write, n is either the input or output tape file number, and s is the serial number of the tape.

(a) The TITLE information is printed.

(b) The statement THIS DATA FILE HAS PLOT OUTPUT ON FILE NUMBER n ON UNIT k WITH LENGTH t - m FEET if the TAPE option appears on a plot command (section 6.1.3).

(c) The statement THIS DATA FILE HAS PLOT PUNCH OUTPUT if the PUNCH option appears on a plot command (section 6.1.2).

(d) The statement OUTPUT IS FOR INPUT FILE n ON UNIT k appears if the input media is tape (section 5).

(e) The statement TAPE OUTPUT ON FILE NUMBER n ON UNIT k is printed if there is tape output (section 4.4).

(f) The statement THE LENGTH RANGE FOR TAPE FILE OUTPUT IS t - m FEET if there is tape output (sections 4.4 and 5.7.1).

(g) The statement(s) THE SERIAL NUMBER FOR TAPE ON UNIT k IS s (section 5.7.1) if the serial number s is specifically defined for any tape unit.

(h) The statement THE NUMBER OF SCANS IS j is printed.

4.2 Printed Table Output for ID's and Variables

The user can specify a list of identifiers whose values are to be printed in a table. Each identifier is assigned its own table, which will begin on a new page of output. The page format is the following:

(a) The set of TITLE command fields appear (blank fields are included).

(b) The statement OUTPUT IS FOR INPUT FILE n ON UNIT k appears if the input media is tape (section 5).

(c) The statement THE FOLLOWING VALUES ARE FOR "name" "dimension type."

(d) A sequence of 1 to 10 scan numbers appears in 10I12 format.

(e) A sequence of 1 to 10 data values appears in 10 (1PE12.4) format.

(f) A blank line appears to separate sets of values.

(g) Lines d through f are repeated until all data is listed.

If a new page is needed, lines a-c will be repeated at the top of the page. The command used to generate the tables is TABLE.

Example: TABLE PS, PC1, PC2, X

4.3 Punched Card Output for ID's and Variables

The user can specify a list of names whose values are to be punched on cards (see also section 6.1.2). For each file in which the punch request is made, a complete set of scan and data values will be puched for each identifier in the order that the name appears on the list. The structure of the punched card output is the following:

(a) Identifier Set - Each identifier has all its information punched in the following form:

(1) Name Card - Identifier name in A10 form.
(2) Information Records - The number of data values is subdivided

into a sequence of records that corresponds to the number of points that can be stored internally for each identifier. The record form is the following:

- Number of values on record.
- Sequence of cards containing all the scan numbers for the record in 6I12 format.
- Sequence of cards containing all the data points for the record in 1P6E12.4 format.

(3) The records are repeated until all values are punched.

(4) End-of-set indicator - The number 9999 is punched in I12 format to indicate the end of the values for the identifier.

(b) The sets are repeated until all information is punched.

(c) End-of-File Indicator - The name IEOF is punched in A10 format to indicate no more punch output this file.

Information about the punched output appears in the system identifier table (Y/appears under PUNCH in the PUNCH/TAPE/PLOT column, section 4.1).

The command used to generate the punch information is PUNCH. The identifiers in the list can be ID's, variables, time and manual setting but not constants.

Example: PUNCH PS, PC1, QC1

It is possible to limit the range of values of the identifiers in the list (a maximum of seven names can be limited).

Example: PUNCH PS, PC1 (0.1, 0.5)

Only those values of PC1 that fall in the range 0.1 to 0.5 will be punched.

4.4 Tape Output for ID's and Variables

The user can specify a list of identifiers whose values are to be written on tape. The output structure is exactly the same as for PUNCH (section 4.3 a-c) except for two differences: (1) There is no Fortran format since information is written on a binary tape, (2) after the end-of-file indicator, a tape end-of-file mark is also generated.

Information concerning the tape output is printed in the system identifier table (Y/appears under TAPE in the PUNCH/TAPE/PLOT column, section 4.1).

The system automatically assigns unit 9 for tape output. The file number count is initialized at the beginning of the program and automatically incremented each time there is output from a command file. The system informs the user of the output file count and drive unit information in the system identifier table (section 4.1).

The command used to generate the output is TAPEWT. Its format including the value limits is the same as for PUNCH.

Example: TAPEWT PS, PC1 (.1, .5), QC1

There are two special features that can be included in the tape write command:

(a) Skip file option - The user can specify the number of files to be skipped before generating tape output. This specification has an effect only on the first time the command is executed.

Example: TAPEWT 2, PS, PC1

The first two files that already exist on the tape will be skipped. The first new output file will be the newly created third file containing data for PS and PC1. The next output file used for the next command file will be the fourth file.

(b) Change unit option - The user can change the logical unit number of the output. This feature is especially useful when used with the tape reread feature (section 5.4) since data can be written on one unit defined as output and then the same unit can be redefined as input. Hence, the tape unit serves as a scratchpad for storing data. However, to effectively use this feature, certain advanced tape features must be known (section 5.7).

Example: TAPEWT (10) 3,PC1

The logical unit 10 replaces the previously defined logical unit as the system tape output unit. All future TAPEWT commands will apply to unit 10. Only one output unit can be assigned for a given command file. For the above example, immediately after the new assignment, three files will be skipped on unit 10. The file count on the previously defined logical unit will remain the same. Switching tape output units does not erase the list of identifiers in the tape output table.

4.5 Scan Table for ID's and Variables

If the channel input option is standard tape, the scan feature can be used to examine the state of the system at special points. The manual

reading can be changed at critical points in the recording. These readings can then be specified on a SCAN command.

The program will output a scan table with scan numbers corresponding to the last time the respective manual settings appeared on the tape. The user can then refer to the printed table output (section 4.2) to find the corresponding values of any ID's or VAR's of interest. There can be a maximum of 50 manual settings for any given file.

Example: SCAN 111111, 111112, 111113

4.6 Constant Identifier Table

The user can specify a list of constant identifier names whose values are to be printed in a table. The table appears on a separate page with the set of TITLE headings, and the following lines corresponding to each identifier.

"name" = "value" with 1PE20.8 format. The list is specified on

the CTABLE command.

Example: CTABLE CONI, PAMB

4.7 Time and Manual Entry Features

These features apply only to the standard tape input and RETAPE (where standard tape was the original input) options. In this case the system has two special identifiers defined to represent the time (TIME) and manual (MANUAL) entry. These identifiers can be used in the same manner as any user defined identifier. Hence, they can appear in any output command (e.g., print, punch, tape, or plot) and can appear in variable expressions. The TIME values are saved in units of seconds. These identifiers use the output format of 10F12.0 for printed tables and 6F12.0 for punched cards rather than the standard formats. There are two special commands associated with these identifiers.

4.7.1 Saving TIME and MANUAL Entry

Normally, the time and manual entry values are not saved by the system except for the production of minimum and maximum values in the System Identifier Table. The SAVE command can be used to save these values. Without this command, these special identifiers cannot be used in any output command.

Example: SAVE MANUAL, TIME

The SAVE command can list either/both identifiers in any order. If only a sampling of the values is desired, the user can specify a storage resolution factor, similar to DELTX.

Example: SAVE TIME (1.), MANUAL (2.0)

For this example, only when time changes by one second will a new point be stored. The manual setting must change by 2.

4.7.2 Listing TIME and MANUAL Entry

This option allows the time and manual entry to be printed as tables in exactly the same manner as TABLE with two exceptions: (1) The settings are printed in 10F12.0 format and (2) the time values are 6 digit numbers of the form HHMMSS representing hours (HH), minutes (MM) and seconds (SS).

Example: LIST TIME, MANUAL

5. Channel Input Specification

This section discusses the permissible forms of channel input that can be used in the program. The input media can be either card or magnetic tape. There are six specific input forms described. The specification is made on the CHINP command. If the input is tape, the tape units will use the logical unit numbers 9, 10, and 14. The file count for each logical unit is maintained by the system, and is automatically incremented as each data file is either read or skipped. It is assumed that each data file contains information to be acted upon by the corresponding command file. Although only one form of input can be used in any one file, the forms can be mixed through the entire program. The statement OUTPUT IS FOR INPUT FILE NUMBER n ON UNIT k is printed after the TITLE information on all output tables, provided the input is tape. The most recently defined CHINP command applies to the present data file and all future data files until a new command is defined.

5.1 Standard Input Tape

The system was primarily designed for this form of input although the other five forms do apply. It is assumed that the data have been recorded on a digital tape recorder* in a format that has the following characteristics:

(a) Data rate - 556 bpi

(b) Width - 7 track

*The recorder used at HDL is a type 1708-CR manufactured by Kennedy Co.

(c) File structure - each file has an unspecified number of records concluding with an end-of-file mark. Each record consists of up to 512 characters coded in BCD (binary-coded-decimal). Each data item (channel input, manual entry, or time) consists of 16 characters.

There are three basic formats for the data items:

(a) Manual entry - A six -digit integer appears anywhere in 5-14 characters and the code M appears in 15-16 characters of this 16-character data item.

(b) Time - The time appears in "hours. minutes. seconds" in characters 5-14 in the form XX.XX.XX where X is a digit. The code H appears in characters 15-16.

(c) Channel input - An integer number 00-99 appears in characters 3-4 representing the channel number. A decimal number consisting of four digits and a decimal point located in front of or after any digit (with or without a leading sign + or -) can be placed anywhere in characters 5-14. (This represents recorded data.) A unit code V or MV appears in characters 15-16.

All characters not used in describing the data should be blank. The sequence of any scan should be manual entry, time, and then all the channel recordings. The option used to specify standard tape is TAPE.

Example: CHINP TAPE

There are two special tape input features:

(1) Skip file parameter - The user can specify how many files to skip before reading the desired file. Unlike the TAPEWT skip file parameter (section 4.4), this one is used for future command files until a new CHINP command is scanned. The parameter is separated from TAPE by a "/."

Example: CHINP TAPE/1

The present command file will skip one data file before reading data. All succeeding command files will skip every other data file until a new CHINP command is scanned.

(2) Bad Point Limit - If there are readings that cannot be understood (incorrect format recorded), the system outputs an error message indicating the scan number and the 16-character channel recording (section 9.2-error 5). The system initially sets the upper limit on the allowable total of bad recordings to 50. Each time a bad reading is scanned, the count is decremented. When it reaches zero, the program is stopped, and an error message

is printed (section 9.2-error 6). The standard tape input always uses logical unit 14.

The user can reset the bad point count to any limit he desires by specifying *"limit" as the last information on the CHINP command after the TAPE option.

Example: CHINP TAPE* 80

This will reset the bad point limit to 80 for the file in which the CHINP command was scanned. However, the limit reset does not carry over onto the new command files as the skip file parameter does. Hence, the "*k" must be repeated for every file for which the limit should be reset.

Note: One must use TAPE/n * k. The form TAPE *k/n is not acceptable.

5.2 Standard Format Card

For this case, the data file is designed in a standard manner. Each file is headed by a set of comment cards (indicated by CC in Columns 1-2). Each scan consists of two cards, each with format 10F8.3. Hence, a maximum of 20 channels can be recorded. The channel numbers are assumed to be recorded in ascending order starting with channel 0; hence no channel number need be specified in the data file. The end of the file is indicated by setting the first channel value to 99999., and leaving the other fields on the two cards blank.

The input option for this command is STCARD. The entire format is CHINP STCARD/N, NC where N is the number of channels recorded and NC is the number of comment cards.

Example: CHINP STCARD/10,3

5.3 User Specified Format Card

This option is similar to the standard card format (section 5.2) except that there are no comment cards, and the user specifies the data format. There can be an arbitrary number of channels per scan appearing on an arbitrary number of cards. The channel numbering sequence and end-of-file indication is the same as for the standard format option.

The option format is CHINP CARD/N, (format) where N is the number of channels per scan and the format (any FORTRAN IV format for real numbers is acceptable) is enclosed in parentheses.

Example: CHINP CARD/35, (10F8.2)

For this case, there are 10 channels recorded per card and four cards per scan necessary to represent 35 channels, referred to as channels 0-34 in the ID commands. The last set of 4 cards will be blank except for 99999. located in the first eight columns of the first card. It is permissiable to mix formats.

Example: CHINP CARD/3, (E12.6, 2F10.2)

5.4 Processed Data on Tape

For this case, the data to be read have been produced from a previous program using the TAPEWT command (section 4.4). The system will scan the data file for identifier names that have been declared in the present program as channel ID's (TIME and MANUAL are also considered ID's and their data saved if the SAVE command is specified). The data corresponding to these names will be stored, and the remaining data are ignored. The ID features (e.g., LIMIT, DELTX, etc.) that apply to input data in section 2 do not apply to processed input data. The system initially assigns logical unit 10 to this tape option. The command field for this option is RETAPE.

Example: CHINP RETAPE

There are two special features that can be used with this option:

(a) Skip file parameter - The user can specify how many files to skip before reading the desired file. As with the TAPE case (section 5.1), this parameter causes file skips in future command files unless the CHINP command is changed.

Example: CHINP RETAPE/4

The first four files are skipped, the fifth file is read, the next four files are skipped, etc.

(b) Change unit option - The user can specify a new logical unit that will now be used for all future RETAPE operations. This feature is tied together with the TAPEWT feature (section 4.4-b). Only one unit can be used per command file for the RETAPE option.

Example: CHINP RETAPE (9)

The logical unit 9 replaces any previously defined RETAPE unit.

Only units 9 and 10 can be used for the TAPEWT and RETAPE features. Neither unit 9 nor 10 can be used for both TAPEWT and RETAPE in the same command file. Also, if both logical units are defined for either tape input or output, they cannot both be used in the same command file.

The skip file option must appear after the logical unit assignment, e.g., RETAPE (9)/4 is correct.

5.5 Processed Data on Cards

For this case, the data to be read were previously generated using the PUNCH command (section 4.3). The ID features that apply to input data in section 2 do not apply to processed data. The data cards may be combined in any way as long as the output form described for the PUNCH command is obeyed. This form essentially consists of a group of identifier data sets followed by an IEOF card for each file. The option specified is CPUNCH.

Example: CHINP CPUNCH

5.6 FORTRAN Formatted Tape

If the data were collected on a tape using FORTRAN compatible formatting (i.e., the data can be read by using standard FORTRAN I/O commands), then these data can be read into the program using an option similar to the card format (section 5.3). There can be an arbitrary number of channels per scan with the limit that any record length within the scan cannot exceed a total of 168 characters. The channel number sequencing is the same as for cards but the end-of-file-indicator is any value greater than or equal to 10^{29}. As in the card case, the last scan with the end-of-file indicator must have a complete set of values, even though all values except the first will be ignored once this value is recognized as the end-of-file indicator.

The option form is CHINP TAPE, N, (format) where N is the number of channels per scan, and the format is any acceptable FORTRAN format.

Example: CHINP TAPE, 20, (5E11.3)

Each record consists of 55 characters representing 5 of the 20 channel values.

As in the other tape options, there is a skip file parameter that can be used.

Example: CHINP TAPE/3, 5, (5E11.3)

The first 3 files are skipped before the desired data file is read. The parameter applies to future command files as well. The logical unit used for this option is 14. The system differentiates between FORTRAN format and standard tape (section 5.1) by checking for the format field. As with the card input, it is permissible to mix formats.

5.7 Advanced Tape Features

There are three special tape commands available to the program to make the handling of the tape I/O easier. They are FILE, REWIND, and SKPFLE. These commands apply to the logical units 9, 10, and 14. It is important to remember that the system automatically handles the file count on the three units, and that the count is independent of the unit's status as input or output.

5.7.1 Tape File Description

The user may alter the system account information with respect to many of the tape features. There are four specific options that can be specified on the FILE command:

(a) User-defined file count - The user can change the file count maintained by the system for a given tape unit (sections 4.4, 5.1, 5.4, and 5.6). On this command he can define the file count for any of the three tape logical units (9, 10, and 14). The system initializes the count to the specified value before beginning the execution of the present command file. Since the count will automatically be incremented when the tape file is actually read, the user should specify the count as one less than the true value for that file. Hence, if the present data file count on unit 14 will be 7, the user should specify 6 on his FILE command.

Example: FILE COUNT (14) = 6

(b) Multi-tape output - The user may request more output (TAPEWT) than can fit on a single tape. The system checks at the beginning of any file that uses a TAPEWT command to see if the present usage of the output has exceeded 2,200 feet. If it has, and no specified backup tape is available, the program is stopped, and the message PROGRAM STOP FROM EXCESS TAPE OUTPUT is printed. The user can circumvent this system halt by listing a set of backup tapes to be used if necessary. The serial numbers of these tapes are specified on a SPILL command and are printed at the top of the System Identifier Table when utilized (section 4.1). The last one listed will be used first. There can be up to 5 backup tapes listed.

Example: FILE SPILL (496, 2201, U0007)

In submitting the job (section 9.1), the user should also indicate to the operator that these tapes may be used.

(c) Tape length specification - At the beginning of the program, the system initializes the length of the output of the tape as zero on units 9 and 10. As the program is run, the system records the length of

each output file in a table (only the first 466 tape files can be recorded). However, when using a tape for output that was partially filled from a previous program run, the system will not know the length of the already generated files and will be forced to use the value zero. To avoid the use of the zero value, the user can specify, on the LENGTH field, the length (in feet) of the tape output that occurred at the end of a given file.

Example: FILE LENGTH (9,6) = 800.

The tape output for the first six files is 800 feet for unit 9.

Example: FILE LENGTH (9,4) = 422., LENGTH (9,5) = 442.

The length of the tape output for file 5 is 20 feet.

(d) Mounting new tapes - Normally the user specifies on his run slip (section 9.1) what tapes should be mounted on which units. However, the user can specifically define these tapes on the MOUNT field. This option especially allows the user to mount new tapes on units 9, 10, and 14 during the execution of his program.

Example: FILE MOUNT (14,U0007), MOUNT (10,452)

The tape with serial number U0007 will be mounted on unit 14, and the tape with serial number 452 will be mounted on unit 10. The MOUNT option causes the following operations:

(1) Program is stopped to allow new tape to be mounted.
(2) Present tape is rewound.
(3) File count is zeroed.
(4) Length of tape output set to 0.
(5) Message to operator.

If the user specifies a serial number for a tape unit in the MOUNT option, the unit and serial number will appear in the system identifier table (section 4.1).

5.7.2 Rewinding Tape Unit

In order to make full use of the RETAPE and TAPEWT features, the user must be able to rewind the tape after writing data so that this information can later be read using RETAPE. The command for doing this is REWIND N where N can be the logical unit 9, 10, or 14. The command applies only to the command file in which it appears. The file count is automatically reset to 0 before any new I/O operation is performed.

Example: REWIND 10

Regardless of where this command appears in the command file, it will be executed before any I/O feature using the specified logical unit.

5.7.3 Skip File List

For the TAPE (section 5.1) and RETAPE (section 5.4) options, the skip file parameter allows the user to specify a set of files to skip. The SKPFLE command allows the user, at the beginning of his program, to define a set of files to be skipped with respect to the logical input units. There is a limit of 20 files that can be so defined. The system will automatically skip these files whenever their file count is reached.

Example: SKPFLE 14(1,6,10), 10(2,3,6)

Files 1, 6, and 10 will be skipped on unit 14 and 2, 3, and 6 will be skipped on unit 10.

6. User Defined Plots

This section describes the two commands PLOT and LABELn that are used to define specific plots and labels for these plots. Three other commands are also described: COMMON, GRAPH, and UPDATE, which are used for scaling blocks of identifiers for plots.

6.1 Plot Command

The user can specify on a PLOT command a set of curves to be drawn on a single plot. A list of identifier names are specified. The first is the independent name, and the rest are dependent. Any identifier name including TIME and MANUAL may be specified.

Example: PLOT (PS, QS, PC1)

The curves QS vs PS and PC1 vs PS will both be drawn on the same plot. The curves are automatically scaled so that the values will all fit on a 5 in. x 5 in. plot.

The appropriate name and its assigned dimension type appears on both the X and Y axis. There is one axis drawn for each X- or Y-name, so that the system information about the curve can be given. Also appearing on the axis is the scale information marked at every inch. The system automatically spaces between plots. Once the plot is defined, it will be

used in future command files, unless specifically reset by the user. If there are no values stored for a given identifier, the curve for that identifier will not be drawn.

Restrictions:

(a) There can be up to 5 dependent names for each independent name on one plot.
(b) There can be up to 2 independent names on one plot.
(c) There can be up to 20 plots defined for any command file.

There are many features associated with the PLOT command that make it more useful.

6.1.1 Multiple Plots

The user can define two sets of curves to appear on the same plot.

Example: PLOT (X, Y) (A, B)

The curves Y vs X and B vs A will appear on the same plot. There will be two X-axes (one for X, one for A, and two Y-axes (one for Y and one for B).

6.1.2 Punching the Plot Data

The user can specify that the plot data be punched.

Example: PLOT PUNCH, (X, Y, Z)

A set of cards will be punched for Y vs X data and for Z vs X data. For each curve punched, the output format is:

(a) The first card gives the information about the independent and dependent names and the number of points for the curve. The exact format is shown below:

PLOT OF	'X-name'	VS	'Y-name'	FOR	n	POINTS
8H	A10	2H	A10	3H	I10	8H

(b) All the independent name values are punched using 1P6E12.4 format.

(c) All the dependent name values are punched using 1P6E12.4 format. The above format makes it easy for the user to enter these data into a FORTRAN program independent of the FLUID system. All cards punched from plot data are produced before the cards generated by the PUNCH command

(section 4.3). Information about the plot punch output appears in the system identifier table (section 4.1).

6.1.3 Taping the Plot Data

The user can also specify that the plot data be written on tape to be used in another FORTRAN program independent of the FLUID system.

Example: PLOT TAPE (9), (X, Y)

The Y vs X data will be written on logical unit 9. (The user must specify either the units 9 or 10 on any plot command using the tape feature. All plot commands for a given command file must specify the same logical unit.) After all the plot data desired have been written, an end-of-file mark is generated before any tape output is generated for a TAPEWT command on the same logical unit. Information about the plot tape output appears in the system identifier table (section 4.1).

The following information is written for each curve in the plot (remember the data are written in binary form and hence no Fortran format):

(a) The first record contains the independent name, dependent name, and number of points.
(b) The next set of records contains the independent name values.
(c) The next set of records contains the dependent name values.

6.1.4 Marking the Curves

If the user finds it difficult to distinguish between curves on a plot, he can specify that special marks be placed on each curve. There are 10 types of marks: □ ⬭ △ + X ◇ ↑ X̄ Z Y. The system will use the first type for the first curve and continue matching marks with each successive curve.

Example: PLOT MARK, (X, Y, Z)

The curve Y vs X will have a "□" placed at every point on the curve, and the curve Z vs X will have a "⬭" placed at every point. The mark will also appear next to the name on the dependent axis so that the user can easily identify each curve. To avoid placing a mark at every point, the user can specify MARK(n) where n is an integer value representing the frequency at which marks should be placed (e.g., MARK(10) means place a mark at every tenth point). If n is negative, the marks without the line will be drawn.

6.1.5 Specifying Axis Length

The user can override the standard 5 in. x 5 in. axis size by specifying his own dimensions.

Example: PLOT 6. 8., (PS, PC1)

The X-axis will be 6 in. long, and the Y-axis will be 8 in. long.

6.1.6 Specifying Scale Information

The user can override the automatic scaling feature by using the SCALE option. If plot limits are specified, all data points outside this range are ignored. For each discarded point, the curve will be drawn connecting the preceding point with the next acceptable value. Hence, the user must be careful in choosing his limits and interpreting the plot. Also, the user can specify whether the scaling algorithm should be the same as the automatic one, but based on the user specified limits (user specifies STD), or if the scaling algorithm should use a scale factor obtained by taking the axis length and dividing by the absolute value of the difference between the specified upper and lower limits (user specifies NSTD). The SCALE option can be used for any/all the identifiers on the plot list.

Example: PLOT (SCALE, PS, 0., 20., NSTD, SCALE, QS, 0.2, 12, STD)

The curve QS vs PS will be plotted with only those PS values that lie between 0 and 20 and those QS values that lie between 0.2 and 12. The X-axis will be scaled to 20/5 = 4 units per inch, and the Y-axis will be scaled by the system. The five fields specified in order are SCALE, name, lower limit, upper limit, scale type.

6.1.7 Ordering of the Plot Command

The following is the ordering of specifications on the PLOT command:
(a) Punch feature, if desired.
(b) Tape feature, if desired.
(c) Mark feature, if desired.
(d) Axis length, if desired.
(e) Plot name list.
(f) Second plot name list, if desired.

Option (a) - (d) apply to both plot name lists. Each specification is separated from the next with a "," indicator.

6.1.8 Common Scale Feature

The user can specify that all the dependent names on a given plot are to have the same scale factor based on the maximum and minimum values of all the dependent names. The PLOT command takes on the following form:

PLOT (X, COMMON/Y1, Y2...)

or PLOT (X, COMMON/SCALE, [STD or NSTD],

lower bound, upper bound, Y1, Y2,...)

In the former case, by specifying "COMMON/", all the dependent names Y1, Y2,... will have the same computed scale factor.

In the latter case by specifying "COMMON/" followed by scale information, all the dependent names Y1, Y2,... will have the same specified scale features. This latter option is simply an abbreviated form of the already available SCALE feature. With the single name SCALE feature, one could use PLOT (PS, SCALE, PC1, 0.1, 0.5, STD, SCALE, PC2, 0.1, 0.5, STD). However, the multiple name scale feature allows the following use:

PLOT (PS, COMMON/SCALE, STD, 0.1, 0.5, PC1, PC2)

In computing the scale factor, when upper and lower bounds are not specified, the system finds the maximum value of all the identifiers and the minimum value of all the identifiers and then uses these two values to obtain the proper scale factor.

Example: PLOT MARK, 6., 8., (PS, COMMON/QS, QC1)

The curves for QS vs PS and QC1 vs PS will have the same scale factor for the Y-axis.

6.2 Label Command

The user can define a label to appear above a plot generated by a PLOT command. The command LABELn causes its character field columns 7-72 to be printed above the corresponding plot in two rows, the first row containing columns 7-36 and the second row containing columns 37-72. The label characters are spread out to cover the entire plot width. If the digit n is between 1 and 9, the LABELn command goes with the n^{th} PLOT defined in the program. If the digit n is "0", the LABEL0 command goes with the PLOT command defined most recently in the program.

Example:

```
LABEL1    PLOT 1
LABEL2    PLOT 2
PLOT      (X,Y)
PLOT      (X,Z)
PLOT      (X,W)
LABELO    PLOT 3
PLOT      (X,T)
LABELO    PLOT 4
```

The first plot Y vs X has the label "PLOT 1". The second plot Z vs X has the label "PLOT 2".

The third plot W vs X has the label "PLOT 3" and the fourth plot T vs X has the label "PLOT 4".

6.3 Common Block Definition

This feature expands greatly the common scale feature described earlier (section 6.1.8). The user can now define a set of identifiers to belong to a common block. This block is referenced by an index number. The block has an upper and lower bound that is a function of its identifier list automatically computed in any command that references the block index.

6.3.1 COMMON Command

This command is used to define the common block.

Example: COMMON   1(QC1, QC3, QC5), 2(PC1, PC3, PC5)

The user specifies a sequence of names that he wishes to be used in defining a common set of upper and lower bounds. In this case QC1, QC3, and QC5 define bounds referenced as common block 1. PC1, PC3, and PC5 define common bounds referenced as common block 2.

The user can define up to 12 common blocks (with index 1-12) and can define up to 5 names at any one time for each block.

6.3.2 Common Block Reference

The user can refer to the common block in one of two ways:
(a) PLOT command or (b) UPDATE command.

(a) Plot command reference

There are three forms of the plot command reference: Each form has the general order ("independent name," COMMON "form operator" "block index")

(1) Initialize form - This form is actually just another structure of the common scale feature definition and is referenced by the " - " form operator.

```
COMMON    1(PC1, PC3)
PLOT      (PS, COMMON - 1)
PLOT      (QC1, COMMON - 1)
```

is the same as

```
PLOT (PS, COMMON/PC1, PC3)
PLOT (QC1, COMMON/PC1, PC3)
```

Each time the PLOT command is executed, the bounds for common block 1, and, hence, the scale factor for the plot will be computed based on the present limits of PC1 and PC3. This form simply saves writing out the list of names each time a different plot involving those names is desired.

(2) Update form - This form uses the present limits of the dependent names in the block to update the block scale factor set from the PLOT or UPDATE commands of previous files if either the previous upper or lower bound is exceeded. The form operator is "/."

Example:

```
COMMON    1(PC1, PC3)
PLOT      (PS, COMMON/1)
```

The "/" acts as the " - " operator if it is the first time that a block has been referenced in a PLOT command.

(3) Non-update form - This form uses the scale factor computed from the previous block reference in a PLOT or UPDATE command for the present PLOT command.

Example: `PLOT (PS, COMMON * 1)`

The "*" acts as the " - " operator if it is the first time that a block has been referenced in a PLOT or UPDATE command. This form allows the user to have exactly the same scale factor for plots from various command files that have the same common block index so that they can be more easily compared.

There can be a problem with this form. If the first file does not contain the largest range for a given common block, then data points are discarded in the plots of subsequent files if their values fall too far outside the initial common block range. Points will be discarded if they fall more than 0.9" below the X-axis or more than 10.9" above the X-axis. Plots with discarded points are treated as those which have data exceeding user specified plot limits (section 6.1.6). This problem is solved by using the UPDATE command to be described later.

For all three forms, the entire block list does not have to be used in computing the scale factor for a given plot.

```
Example:  COMMON    1(QC1, QC3, QC5)
          PLOT      (PS, COMMON/1, QC1, QC3)
          PLOT      (PS, COMMON/1, QC1, QC9, QC2, QC4, QC6)
```

In the first plot, only QC1 and QC3 are used to update the scale factor. In the second plot, QC1 and four new identifiers that do not even appear in the block definition are used to update the block limits. There is a limit of five identifiers that can be listed in the common option of the plot command.

(b) Update Reference - The UPDATE command allows the user to update the limits for a given common block without actually generating a plot.

```
Example:  COMMON    1(QC1, QC3), 2(PC1, PC3)
          UPDATE    1, 2
```

The limits for blocks 1 and 2 will be updated every file unless the UPDATE command is reset.

As in the PLOT CASE, the user can specify a list of names (not all belonging to that block) to be used, rather than the entire block list in updating the scale factor.

To avoid the problem of discarded data associated with the non-update form of the PLOT command and yet have one common scale factor for plots generated throughout the program, the user can process all his data and save it by using TAPEWT. He then reads the data back in using REWIND and RETAPE and performs the actual plots using the updated scale factors based on all of the data.

```
Example:  UPDATE    1, 2(PC1)
```

An example of such a program is shown in figure 2. It is desired to have two plots, P01 vs PS and P02 vs PS in each plot, made from data PS, P01, P02 in data files 1 and 2 on the standard tape input. In the first two command files, the data are read, the scale factor is updated, and the data are stored back on tape. After the tape is rewound, the processed data are now reread, and the plots drawn, both with the proper identical scale factor.

There is an option on the UPDATE command that, when used in conjunction with the GRAPH command, allows the user to plot up to 24 curves from various data files on a single plot with common scale factors.

```
Example:  UPDATE     1/PS (PC1, PC3)
```

Whenever a "/name" appears, the system assumes a curve is to be generated with the independent identifier for that command file being the specified name. Hence, the system automatically saves on disk the data for the curves PC1 vs PS and PC3 vs PS. The system also maintains the lower and upper limits of the X-axis identifier. The independent identifier's name can change for the same COMMON block in different command files.

```
Example:  COMMON     1(P01, P02)
          UPDATE     1PC1 (P01)
          END
          UPDATE     1/PC2 (P02)
```

In this case, PC1 is the independent identifier in one file, and PC2 is the independent identifier in the next file.

```
*            DATA IS ON STANDARD TAPE
CHINP        TAPE
ID           PS
ID           P01
ID           P02
COMMON       1 (P01, P02)
TAPEWT       P01, P02, PS
UPDATE       1
END
*            READ SECOND FILE WITH PS, P01, P02 DATA
END
*            READ FIRST FILE AGAIN AND PLOT
REWIND       9
RESET        UPDATE, TAPEWT
CHINP        RETAPE (9)
PLOT         (PS, COMMON *1)
END
*            READ SECOND FILE AGAIN AND PLOT
END
STOP
```

Figure 2. Example of use of UPDATE Command.

Once the data have been saved, they can now be plotted using the GRAPH command.

6.4 GRAPH Command

This command allows the user to plot a set of curves with a common X-Y axis (as opposed to multiple axis for the PLOT command). After having stored the curves using the UPDATE command (section 6.3.2), all the curves for the referenced common block (including those generated in the same command file as the GRAPH command) are plotted when the GRAPH command is executed.

Example: GRAPH 1(PC/PSI, PO/PSI)

The user has specified that all curves saved for common block 1 are to be plotted. When the plotting is done, the GRAPH command is automatically reset, and the curve data is destroyed. The user specifies an X-axis and Y-axis name and can also specify a dimension type. If no type is specified, nothing is printed. However, if "/" is used alone, the default dimension type is printed.

The set of title cards will appear above the plot with a character size determined by the length of the X-axis.

There can be a maximum of 24 curves generated for a single GRAPH command. The X- and Y-axis lengths are automatically set at 5 inches. There are three options available to the user.

(a) Marking the Curves

As with the PLOT command, the user can mark the curves in order to distinguish them (section 6.1.4).

Example: GRAPH 1, MARK (10), (PC, PO)

In addition to the 10 mark types already described, there are four more: ⌶ ✱ ⧗ | . If there are more than 14 curves on a single GRAPH, the type mark will be reinitialized to the first type for the 15th curve.

(b) Specifying Axis Length

The user can override the standard length by specifying his own dimensions:

Example: GRAPH 1, 6., 8., (PC, PO)

The X-axis will be 6" long, and the Y-axis will be 8" long.

The order for the GRAPH fields is:

(a) block number
(b) mark option
(c) axis length option
(d) X-Y name.

Example: The example shown in figure 2 could be simplified by substituting the following commands for those after the COMMON command:

```
UPDATE    1/PS
END
GRAPH     1, (PS, PO)
END
STOP
```

The example in figure 2 would result in two two-curve plots, each designated as PO1 vs PS and PO2 vs PS. The above example would yield a single four-curve plot designated as PO vs PS.

(c) Specifying Scale Factor

The user can specify his own scale limits to be used for the X and Y identifiers. This corresponds to the NSTD feature for PLOT (section 6.1.6) except that no points will be discarded.

Example: GRAPH 1, (PC/PSI*.2, .5, PO/PSI*0.,4.).

The "*" indicates that the lower and upper limits will be specified.

7. Standard Plot Feature

This feature is used to generate the curves that appear on the second page of the Digital Fluidic Component Fact Sheet adopted by the Government Fluidics Coordination Group (GFCG). A set of five plots that represent the main characteristics of the fluidic device is generated. The set of plots includes the following types (Qx = volumetric flow; Px = pressure).

Type 1. Power characteristic curves - A set of up to four QS vs PS curves may be generated.

Type 2. Control characteristic curves - A set of up to 16 QC_n vs PC_n curves may be generated where n = 0, 1,...,9.

Type 3. Output characteristic curves - A set of up to 16 QO_n vs PO_n curves may be generated where n = 0, 1,...,9.

Type 4. Output recovery curves - A set of up to 8 PO_n (or QO_n) vs PS curves may be generated where n = 0, 1,...,9.

Type 5. Quasi-static input-output transfer characteristic curves - A set of up to 32 PO_n (or QO_n) vs PC_m curves may be generated where n, m = 0, 1,...,9.

Each set of curves is drawn on a 2" x 2" plot with 0.25" between plots (horizontally and vertically). The title commands are printed above the standard plot output. A "+" is placed at the (0,0) point on any plot for which the point exists.

The maximum and minimum of all the control pressures at which the device switches ON (PCSWON) (section 8.2) are indicated above the X axis of plot type 5 with "1" and the maximum and minimum of all the control pressures at which the device switches OFF (PCSWOFF) are indicated in a like manner below the axis.

The names (PO, PC, PS, QO, QC, and QS) appear on the axes along with their dimension type. The name of each identifier (ID or variable) used for these curves must have its first two letters correspond exactly to the above names. (The "O" in PO and QO is the letter "O" and not the number zero.) The name index (e.g., 4 in PC4) must be a single digit.

Letters or digits beyond the first three characters are ignored.

The standard plots are generated using the STDPLT command. The command applies only to the file in which it appears.

Example: STDPLT 2

All QC_n vs PC_n data for the command file in which the command appears is saved for later generation of the type 2 plot.

7.1 Partial Plot Storing

If a list of identifiers appears after the plot index, then only those curves relative to the specified names will be saved. For example, the user may have defined and recorded data for two control pressures (e.g.,

PC1 and PC2) and two output pressures (PO1 and PO2). Type 5 plot data pertinent to only PC1 are in one file, and the data pertinent to only PC2 are in the next file. The user would

```
STDPLT  5(PC1, PO1, PO2)
END
STDPLT  5(PC2, PO1, PO2)
```

7.2 Multiple Plot Storing

The user can specify that more than one type of plot is to be generated in a given command file.

```
Example:  STDPLT   1, 4(PS, PO1, PO2)
          END
          STDPLT   2(PC1, QC1), 5(PC1, PO3, PO4)
```

7.3 On-Off Definition for Plot 3

If not specified by the user, the system assumes that curves defined for plot 3 contain both PO on and PO off data. If PO is increasing, it is assumed to be on. If decreasing, it is assumed off. The user can specify whether the curve is always on or off as follows:

```
Example:  STDPLT    3F(PO1, QO1)
          END
          STDPLT    3N(PO1, QO1)
```

For the first file the user has specified that the QO1 vs PO1 curve is for O1 off (F). For the next file the user has specified that the QO1 vs PO1 curve is for O1 on (N). In the former case there must be a sequence of decreasing values of PO1 recorded, and for the latter case there must be a sequence of increasing values of PO1 recorded. However, for both cases, increasing and decreasing values may have been stored.

7.4 Order that Curves are Saved

The standard printout parameters (section 8) are listed in the same order as the standard plot curves are saved. For non-partial plot types 1, 2, 3, and 4, the curves will be saved in the order that the PO and PC identifiers are listed in the system's internal ID and variable name tables. For non-partial plot type 5, the curves are saved in the following order:

(a) The ID and variable name tables are scanned for the first PO whose values have been created in the file. The list is again scanned for the first PC with an index that is even if PO is even, or odd if

PO is odd. If the PC name has data in this file, the curve is stored. This process, obtaining the on-going (PO (or QO) curves goes from off to on at PCSWON) curves, is repeated for all PC and PO.

(b) Process (a) is repeated where the PC index is now even when the PO index is odd and odd when the PO index is even. This process obtains the off-going (PO (or QO) goes from on to off at PCSWON) curves.

Example: Suppose there are data in this file for PC1, PC2, PO1, and PO2. The curves saved by STDPLT 5 are (in order): PO1 vs PC1, PO2 vs PC2, PO1 vs PC2 and PO2 vs PC1.

7.5 STDPLT Command Restrictions

(a) The STDPLT command should appear only once in a given command file.

(b) The STDPLT command should be reset only if the standard plots are to be output in that file. In that command file no other STDPLT command should appear, and no new data should be read. The RESET STDPLT command outputs the curves (and standard printout, section 8) and then erases all information about the plots. The user can then begin to accumulate new curves in the next command file.

(c) The STOP command will cause the standard plot and printout to be generated.

(d) In standard plot types 4 and 5, if the partial plot storing option is not used, the system will generate curves for the PO parameters only. If the option is used and both PO and QO parameters have been specified, the plot labeling will be determined by the first parameter specified.

(e) For standard plot types 2 and 3, if the partial plot storing option is not used, all PCi identifiers defined at the time a STDPLT 2 is used must be complimented by a currently defined QCi identifier and vice versa. For example, if PC2 is currently defined, QC2 must also be defined, and if QC3 is defined, PC3 must be defined. Similarly, for STDPLT 3, all POj's currently defined must be complimented by QOj's, and vice versa.

8. Standard Printout

This option appears with the standard plot feature. The standard printout and plot combine to form the second page of the Digital Fluidic Component Fact Sheet adopted by the Government Fluidics Coordination

Group (GFCG). The system requires as input the first five parameters (1-3b below) and uses them to compute the remaining eight parameters based on the curves generated from the standard plot. These 11 parameters are printed in the format shown below:

STANDARD PRINTOUT

1. NOZZLE WIDTH =
2. ASPECT RATIO =
3a. SUPPLY PRESSURE (RANGE) =
TO =
3b. PS TYPICAL =
4. POWER CONSUMPTION (WATTS) =
5. FANOUT =
6. FLOW RECOVERY =
7. PRESSURE RECOVERY =
8. FLOW GAIN =
9. POWER GAIN =
10. PRESSURE GAIN =
11. HYSTERESIS =

The output values are printed in F format, allowing for values that fall between 10^{-6} and 10^{8} with up to 8 significant digits printed out.

The first five parameters appear on the standard print command:

STDPRT x_1, x_2, x_3, x_4, x_5

where the x_i's are the values of 1-3b.

In addition to the standard printout parameters, there are many other parameters printed out under the title "SYSTEM VARIABLES." Except for the case of Power Consumption (section 8.1), the computation of the parameters for the standard printout does not take data dimensions into consideration. Therefore, care must be taken to use compatible dimension types for the data.

The following sections describe the computation of the parameters. The notation $y = y\ [f_i(x)]$ means that y is a function of x taken from standard plot i. As an example, QS = QS [f_1 (PSTYPICAL)] indicates that QS is a function of PS taken from plot 1. Whenever a STDPLT command is executed, the appropriate identifier data are stored in a function table. Whenever the x value does not appear as a domain (independent) value in the function table, linear interpolation will be used to obtain the range (dependent) value. For example, in the above illustration, if the exact value of PS = PSTYPICAL is not recorded and hence is not in the function table, then the correct value of QS is found by means of linear interpolation. If a value is outside the domain limits, a range value of 10^{20} is used. This results in the appearance of asterisks in the standard printout.

Since most of the curves have hysteresis loops, one additional index is applied to the function form to describe which function value is to be selected if there is more than one y for a given x.

$$y = y\,[f_i(x)]^n$$

where $n = 0$ choose maximum dependent value

$n = 1$ choose minimum dependent value

$n = 2$ choose dependent value for increasing independent value (i.e., $x_j \geq x_{j-1}$)

$n = 3$ choose decreasing hysteresis value (i.e., $x_j \leq x_j - 1$)

When the index does not appear on the function, its value is assumed to be zero.

8.1 Power Consumption

POWER CONSUMPTION =

$$\text{PS TYPICAL (PA)}* \frac{1.0132 \times 10^5 \text{ *QS}[f_1\text{(PS TYPICAL)] (CMPS)}}{1.0132 \times 10^5 + \text{PS TYPICAL (PA)}} \qquad (8.1)$$

This assumes that PS is gauge pressure referred to standard atmosphere and QS is standard volume flow. Also, the value of QS is averaged if more than one type 1 standard plot was stored.

The power is in watts and assumes the dimension pascals (PA) for pressure and cubic meters per second (CMPS) for flow. If either quantity has another dimension and the user specifies the corresponding dimension type listed in table 8.1 on the appropriate ID or VAR command, a conversion factor is applied to assure that power is in watts. If the dimension type is not one of those listed below, no conversion factor is applied.

PRESSURE			FLOW	
Dimension		Conversion Factor	Dimension x	Conversion Factor
(1)	PA (pascal)	1.	CMPs m^3/sec	1.
(2)	BAR (bar)	10^{-5}	CCPS cm^3/sec	10^{-6}
(3)	KPA (kilopascal)	10^{-3}	LPS l/sec	10^{-3}
(4)	MILBAR (millibar)	10^{-2}	LPM l/min	1.6667×10^{-5}
(5)	PSI (pounds per square inch)	1.4504×10^{-4}	CFS ft^3/sec	2.8317×10^{-2}
(6)	INH20 (inches of water)	4.0186×10^{-3}	CFM ft^3/min	4.7195×10^{-4}
(7)	INHG (inches of mercury)	2.9614×10^{-4}	GPM gal/min	6.3090×10^{-5}
(8)	MMHG (millimeters of mercury)	7.5008×10^{-3}	GPS gal/sec	3.7854×10^{-3}

Table 8.1 Conversion Factors for Computation of Power Consumption.

8.2 Logic Device Control Switch Pressure

In order to compute such parameters as fanout and gain, the control switch points of the logic device must be computed. Figure 3, showing quasi-static input-output transfer characteristics (type 5 curves), illustrates the values of many of the parameters associated with the control switch points that are printed out on the standard data sheet. The mathematical definitions of the parameters are given in the order they appear on the standard printout sheet in table 8.2. It is important to note that the parameters GAINON, POONLIM_{QO} (20), POONLIM_{QO} (33), POOFFLIM_{QO} (20) each have two definitions. The proper choice, indicated in table 8.2, depends upon whether the type 5 curve is ongoing [PO (or QO) goes from OFF to ON at PCSWON] or off-going [PO (or QO) goes from ON to OFF at PCSWON].

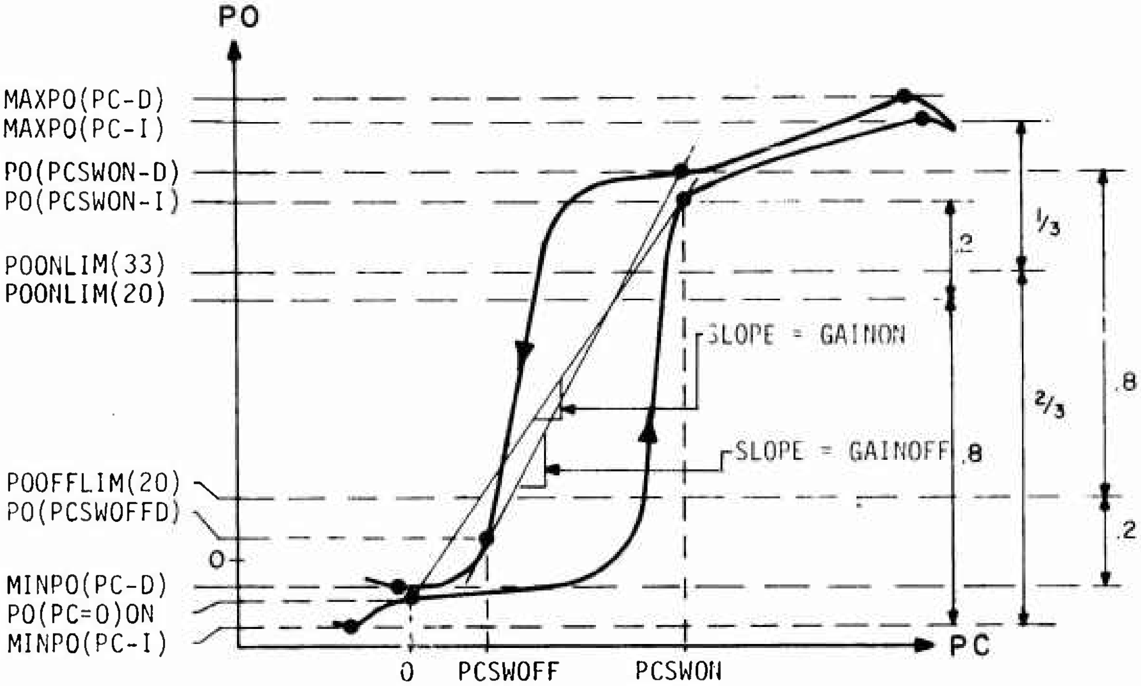

Figure 3(a). Example of ON-GOING type 5 Characteristic Curve.

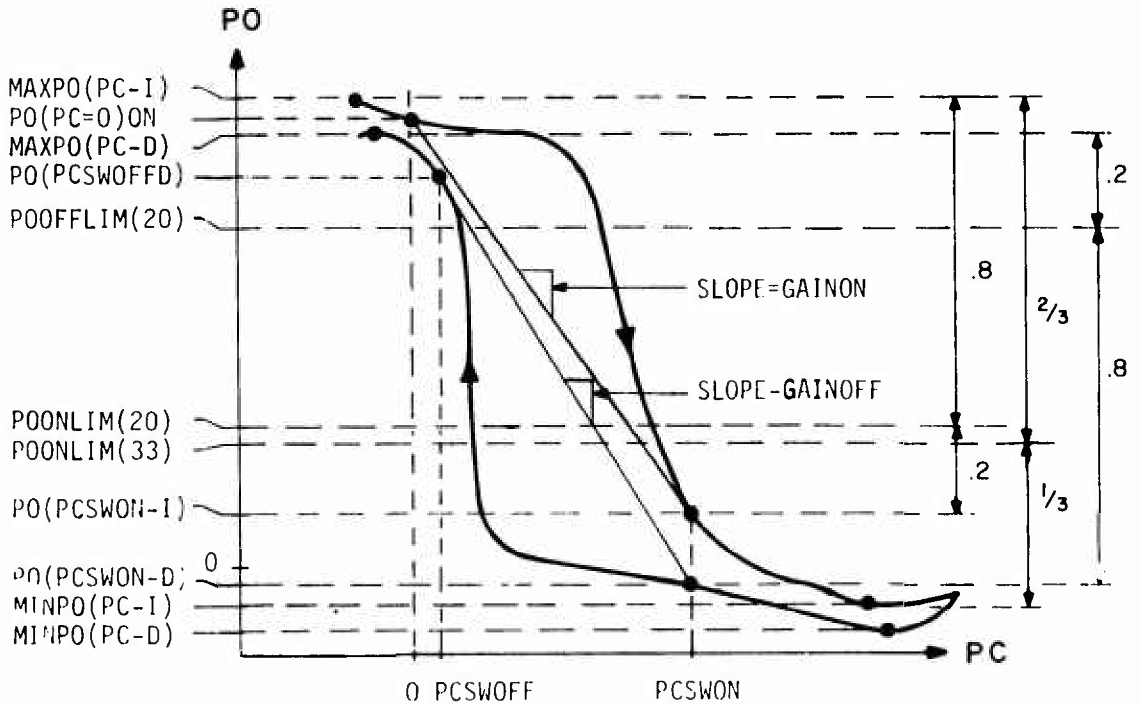

Figure 3(b). Example of OFF-GOING type 5 Characteristic Curve.

There are also a number of parameters listed in table 8.2 that can be either output pressure or output flow functions of the indicated parameters. For example, $\mathrm{MAX}\genfrac{}{}{0pt}{}{\mathrm{PO}}{\mathrm{QO}}\,(\mathrm{PC{-}I})$ is either the maximum output pressure or maximum output flow for all values of PC increasing in a type 5 curve. Maximum pressure is chosen if the curve is for PO_n vs. PC_m, and maximum flow is chosen if QO_n vs. PC_m is specified by the user in the STDPLT command. As for all such pressure or flow parameters, both definitions are listed in table 8.2.

For the ongoing case, the value of PC at which the device switches from the OFF to the ON state (PCSWON) is defined as that value at which the gain (GAINON) is maximized, subject to two conditions (table 8.2). The first condition is that $\genfrac{}{}{0pt}{}{\mathrm{PO}}{\mathrm{QO}}\,[f_5\,(\mathrm{PCSWON})]^2 \geq \genfrac{}{}{0pt}{}{\mathrm{POONLIM}}{\mathrm{QO}}\,(33)$. This insures that a significant change in output level occurs by the time PC = PCSWON is reached. The other condition is that $\genfrac{}{}{0pt}{}{\mathrm{PO}}{\mathrm{QO}}\,[f_5(\mathrm{PC} \geq \mathrm{PCSWON})]^2 \geq \genfrac{}{}{0pt}{}{\mathrm{POONLIM}}{\mathrm{QO}}\,(20)$. This guarantees that the output level change is not just a transient phenomenon and that the unit does not switch off at some higher value of PC.

The value of PC at which the device switches from the ON to the OFF state (PCSWOFF) has a definition similar to PCSWON. In this case, the value of GAINOFF is maximized, subject to one condition (table 8.2). $\genfrac{}{}{0pt}{}{\mathrm{PO}}{\mathrm{QO}}\,[f_5\,(\mathrm{PC} \leq \mathrm{PCSWOFF})]^3 \leq \genfrac{}{}{0pt}{}{\mathrm{POOFFLIM}}{\mathrm{QO}}(20)$ insures that the device has a significant change in output level and that that change is not just a transient phenomenon.

For the offgoing case, there is a change in both the definition of GAINON and the conditions to which it and GAINOFF are subject. This is shown in table 8.2.

The parameters illustrated in figure 3 are computed for each of the curves in plot type 5. The parameter values appear in the standard printout in the order that the curves have been stored in the system (section 7.4).

ITEM NO.	STANDARD PRINTOUT NAME	MATHEMATICAL DEFINITION	REPORT SECTION NUMBERS
1.	NOZZLE WIDTH	NONE	8
2.	ASPECT RATIO	NOZZLE DEPTH/NOZZLE WIDTH	8
3A.	SUPPLY PRESSURE RANGE	NONE	8
3B.	SUPPLY PRESSURE(TYPICAL)	NONE	8
4.	POWER CONSUMPTION	$[\text{SUPPLY PRESSURE(TYPICAL)}]\dfrac{1.0132\times10^5 * \overline{QS}[f_1(\text{SUPPLY PRESSURE(TYPICAL)})]}{1.0132\times10^5+[\text{SUPPLY PRESSURE(TYPICAL)}]}$	8
5.	FANOUT	$int[(QOSWON_{MIN}/QCSWONMAX_{MAX}]$	8.3
6.	FLOW RECOVERY	$\overline{QO(PO=0)ON/QS}$	8.4
7.	PRESSURE RECOVERY	$\overline{POMAX/PS}$	8.5
8.	FLOW GAIN	[(QOSWON-AVG)-(QOOFF-AVG)]/[(QCSW-AVG)-(QC(PC=0)AVG)] $[\overline{QO(PCSWON\text{-}I)} - \overline{QO(PC=0)}ON]/[(QCSW\text{-}AVG)-(QC(PC=0)AVG)]$	8.6
9.	POWER GAIN	[(QOPOON-AVG)-(QOPOOFF-AVG)]/(QCSW-AVG)(PCSWON-AVG)	8.7
10.	PRESSURE GAIN	$\lvert[\overline{PO(PCSWON\text{-}I) - PO(PC=0)ON}]/(PCSWON\text{-}AVG)\rvert$ $[\overline{POSWON} - \overline{POF}]/(PCSWON\text{-}AVG)$	8.8
11.	HYSTERESIS	$PCSWON_{MAX}\text{-}PCSWOFF_{MIN}$	8.9
12.	PRESS GAIN	$\left\lvert\left[\dfrac{PO(PCSWON\text{-}I)}{QO} - \dfrac{PO(PC=0)ON}{QO}\right]\right\rvert / (PCSWON\text{-}AVG)$	8.8
13.	PO (PC=0)ON QO	$PO[f_5(0)]^2$ $QO[f_5(0)]^2$	8.8 8.6
14.	MAXPO (PC-I) QO	$PO[f_5]^2_{MAX}$ $QO[f_5]^2_{MAX}$	8.2

Table 8.2 Mathematical Definitions of Standard Printout Parameters

ITEM NO.	STANDARD PRINTOUT NAME	MATHEMATICAL DEFINITION	REPORT SECTION NUMBERS
15.	$\underset{QO}{MINPO}(PC-I)$	$PO[f_5]^2_{MIN}$ $QO[f_5]^2_{MIN}$	8.2
16.	$\underset{QO}{PO}(PCSWON-I)$	$PO[f_5(PCSWON)]^2$ $QO[f_5(PCSWON)]^2$	8.2, 8.8
17.	$\underset{QO}{PO}(PCSWON-D)$	$PO[f_5(PCSWON)]^3$ $QO[f_5(PCSWON)]^3$	8.2
18.	GAINON	$\left\lvert \left[\underset{QO}{PO}[f_5(PC)]^2 - \underset{QO}{MINPO}(PC-I)\right] \Big/ PC \right\rvert_{MAX}$ (ON-GOING CASE) where $\underset{QO}{PO}(PCSWON-I) \geq \underset{QO}{POONLIM}$ (33) and $\underset{QO}{PO}[f_5(PC > PCSWON)]^2 \geq \underset{QO}{POONLIM}$ (20)	8.2
		$\left\lvert \left[\underset{QO}{PO}[f_5(PC)]^2 - \underset{QO}{MAXPO}(PC-I)\right] \Big/ PC \right\rvert_{MAX}$ (OFF GOING CASE) where $\underset{QO}{PO}(PCSWON-I) \leq POONLIM(33)$ and $\underset{QO}{PO}[f_5(PC > PCSWON)]^2 \leq POONLIM(20)$	8.2
19.	GAINOFF	$\left\lvert \left[\underset{QO}{PO}[f_5(PC)]^3 - \underset{QO}{PO}(PCSWON-D)\right] \Big/ (PC - PCSWON) \right\rvert_{MAX}$ where $\underset{QO}{PO}[f_5(PC < PCSWOFF)]^3 \leq POOFFLIM(20)$ (ON-GOING CASE) or $\underset{QO}{PO}[f_5(PC < PCSWOFF)]^3 \geq POOFFLIM(20)$ (OFF-GOING CASE)	8.2

Table 8.2 (cont)

ITEM NO.	STANDARD PRINTOUT NAME	MATHEMATICAL DEFINITION	REPORT SECTION NUMBERS
20.	PCSWON	PC[f_5(GAINON)]	8.2, 8.3,8.7 8.8, 8.9
21.	PCSWOFF	PC[f_5(GAINOFF)]	8.2, 8.3
22.	PO(PCSWOFFD) QO	PO[f_5(PCSWOFF)]^3 QO[f_5(PCSWOFF]^3	8.2
23.	POONLIM(20) QO	.8PO(PCSWON-I) + .2MINPO(PC-I) QO QO	8.2
		.8PO(PCSWON-I) + .2MAXPO(PC-I) QO QO	8.2
24.	POONLIM(33) QO	$\frac{2}{3}$ MAXPO(PC-I) + $\frac{1}{3}$ MINPO(PC-I) QO QO	8.2
		$\frac{2}{3}$ MINPO(PC) + $\frac{1}{3}$ MAXPO(PC-I) QO QO	8.2
·25.	POOFFLIM(20) QO	.2PO(PCSWON-D) + .8MINPO(PC-D) QO QO	8.2
		.2PO(PCSWON-D) + .8MAXPO(PC-D) QO QO	8.2
26.	MAXPO(PC-D) QO	PO$[f_5]^3_{MAX}$ QO$[f_5]^3_{MAX}$	8.2
27.	MINPO(PC-D) QO	PO$[f_5]^3_{MIN}$ QO$[f_5]^3_{MIN}$	8.2

Table 8.2 (cont)

ITEM NO.	STANDARD PRINTOUT NAME	MATHEMATICAL DEFINITION	REPORT SECTION NUMBERS
28.	QC(PC=0)	$QC[f_5(0)]^2$	8.6, 8.8
29.	QCSWONMAX	$QC_i[f_2(PCSWON_{iMAX})]^0$	8.3
30.	QCSWOFFMAX	$QC[f_2(PCSWOFF_{iMAX})]^0$	8.3
31.	QCSWONMIN	$QC[f_2(PCSWON_{iMIN})]^1$	8.3
32.	QCSWOFFMIN	$QC[f_2(PCSWOFF_{iMIN})]$	8.3
33.	FLOW REC.	$QO[f_{3_{ON}}(0)]^2 / QS_{MEAN}$	8.4
		$QO[f_{3_{ON}}(0)]^2 / QS[f_1(PS_{MEAN})]^0$	
		$QO[f_{3_{ON}}(0)]^2$ / QS TYPICAL	
34.	QO(PO=0)ON	$QO[f_{3_{ON}}(0)]^2$	8.4
35.	QO(PO=0)OFF	$QO[f_{3_{OFF}}(0)]^3$ if PO=0	8.6
		$QO[f_{3_{OFF}}(PO_{MIN})]^3$ if $PO \neq 0$	
36.	QOSWON	$QO[f_{3_{ON}}(PCSWON_{MAX})]^{1,2}$	8.3, 8.5

Table 8.2 (cont)

ITEM NO.	STANDARD PRINTOUT NAME	MATHEMATICAL DEFINITION	REPORT SECTION NUMBERS
37.	QOPOMAXON	$\left[QO[f_{3_{ON}}(PO)]^{1,2} \cdot PO\right]_{MAX}$	8.7
38.	QOPOMAXOFF	$\left[QO[f_{3_{OFF}}(PO)]^{1,3} \cdot PO\right]_{MAX}$	8.7
39.	POMAX	$PO[f_{3_{ON}}(QO \geq 0)]^{0,2}_{MAX}$	8.5
40.	PRESS. REC.	$POMAX/PS_{MEAN}$	8.5
41.	QS	QS_{MEAN} $QS_{INITIAL\ VALUE}$	8.4
42.	PS	PS_{MEAN} $PS_{INITIAL\ VALUE}$	8.5
43.	POF	$PO[f_{3_{OFF}}(QC(PC=0)AVG)]^{3}$	8.8
44.	POSWON	$PO[f_{3_{ON}}(QCSW\text{-}AVG)]^{2}$	8.8
45.	QOSWF1	$QO[f_{3_{OFF}}(PCSWOFF_{MIN})]^{0,3}$	8.3
46.	QOSWF2	$QO[f_{3_{OFF}}(PCSWOFF_{MAX})]^{1,3}$	8.3
47.	QOSWF3	$QO[f_{3_{OFF}}(PCSWON_{MIN})]^{0,3}$	8.3

Table 8.2 (cont)

ITEM NO.	STANDARD PRINTOUT NAME	MATHEMATICAL DEFINITION	REPORT SECTION NUMBERS
48.	QSTYPICAL	$QS[f_1(\text{SUPPLY PRESSURE (TYPICAL)})]^0$	8.1, 8.4
49.	PCSWON-AVG	$\overline{PCSWON}$	8.7, 8.8
50.	QC(PC=0)AVG	$\overline{QC(PC=0)}$	8.6, 8.8
51.	QCSW-AVG	$\overline{QCSWONMAX}$	8.6, 8.7, 8.8
52.	QOOFF-AVG	$\overline{QO(PO=0)OFF}$	8.6
53.	QOSWON-AVG	$\overline{QOSWON}$	8.6
54.	QOPOON-AVG	$\overline{QOPOMAXON}$	8.7
55.	QOPOOFF-AVG	$\overline{QOPOMAXOFF}$	8.7
56.	FANOUT	$(QOSWON_{MIN}) / QCSWONMAX_{MAX}$	8.3
57.	OR/NOR	$(QOSWF1_{MAX}) / QCSWOFFMIN_{MIN}$	8.3
58.	FLIP FLOP (OFF)	$(QOSWF2_{MIN}) / QCSWOFFMAX_{MAX}$	8.3
59.	FLIP FLOP (ON)	$(QOSWF3_{MAX}) / QCSWONMIN_{MIN}$	8.3

Table 8.2 (cont)

When the user specifies QO as the parameter for a type 5 standard curve, all references to PO in the above equations must be thought of as references to QO.

8.3 Logic Device Fanout Parameters

Logic device fanout can be thought of as a measure, under worst case conditions, of how many downstream elements can be switched to an on state by a single upstream element that has an output port connected to the controls of those downstream elements. Worst case implies that the port with the least output flow available is used to drive the control ports requiring the highest amount of flow to switch. Mathematically, the fanout is the integer value of the ratio of output flow available over control flow required for switch.

$$\text{Fanout} = \text{int}\ [(\text{QOSWON}_{\text{MIN}})/(\text{QCSWONMAX}_{\text{MAX}})]$$

A separate value for QCSWONMAX is computed for each type 2 curve (QC_i vs PC_i). These values are listed in the standard printout. The value is based on the maximum PCSWON that uses the same index; e.g., given PC3, QC3, PO1, and PO2 data from a file used in the standard plot in the form

STDPLT 2 (PC3, QC3), 5(PC3,PO1,PO2).

The QCSWONMAX value of QC3, computed from the type 2 curve, is based on the larger of the two PCSWON values computed from the type 5 curves (one from PC3 vs PO1, the other from PC3 vs PO2) from that data file. (Since for the GFCG fact sheet, all standard plot data are obtained from a single element, a self-staged fanout will be calculated. If a fanout calculation for the interaction between dissimilar elements were desired, the type 3 curve data should be from the driving element, with the downstream elements supplying the type 2 and 5 curve data.)

$$\text{QCSWONMAX} = QC_i\ [f_2\ (\text{PCSWON}_{i\text{MAX}})]^0$$

where the values of both QC_i and $\text{PCSWON}_{i\text{MAX}}$ are taken from the same type 2 curve.

The largest of all these values ($\text{QCSWONMAX}_{\text{MAX}}$) is used in calculating the fanout.

The other parameter required to calculate fanout is $\text{QOSWON}_{\text{MIN}}$. This is computed as follows:

$$\text{QOSWON} = \text{QO}\ [f_{3_{\text{ON}}}(\text{PCSWON}_{\text{MAX}})]^n$$

where n = 1 if the user specifies that PO is on;

n = 2 if the user does not specify PO as on or off.

Note: No value is computed if PO is specified as off.

A separate value of QOSWON is listed for each type 3 ON curve (QO_i vs PO_i) in the standard printout. Its value is based on the largest PCSWON value computed from all type 5 curves. The minimum value of QOSWON computed in this manner is used in the calculation of fanout.

Figure 4 illustrates the nonrepeatability of the type 5 characteristic curves for pressure sweeps at several control ports of an element. As has been stated, worst-case fanout considers this nonrepeatability by considering the maximum value of PCSWON. Other useful parameters are described below.

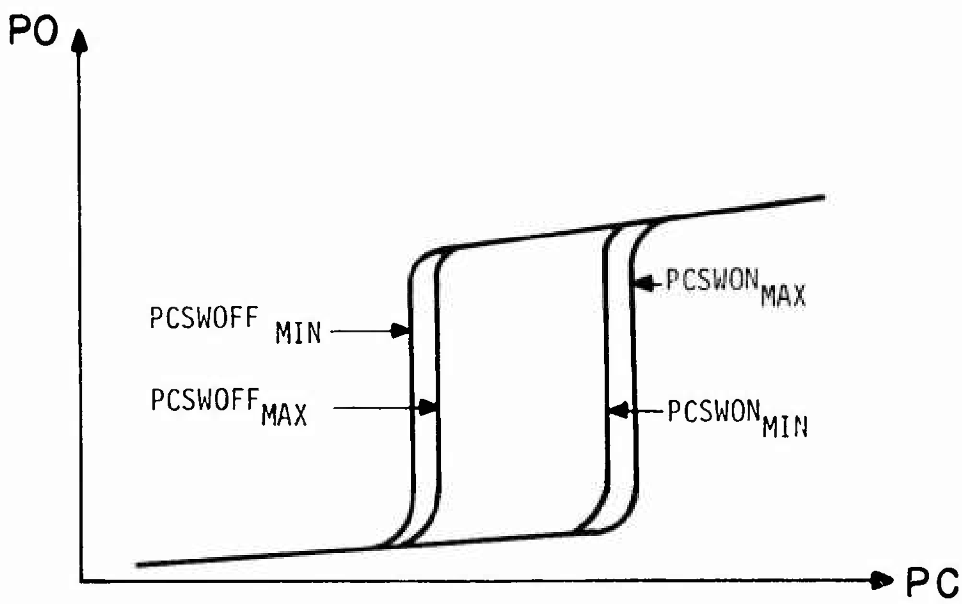

Figure 4. Example of Nonrepeatability of type 5 Characteristic Curves.

In addition to knowing how many downstream elements can be switched to the on state when an upstream element is switched on, a digital circuit designer is also interested in knowing what effect an upstream element in the off state has on downstream elements.

At the bottom of the standard printout, in addition to the non-integer value of fanout, parameters, titled OR/NOR, FLIP FLOP(OFF), and FLIP FLOP(ON), which are related to the mode in which the element functions, are listed. Values of these parameters are listed for each possible fanout, up to and including the element's calculated maximum integer value. Listed below this, a specification of the range of fanouts over which the element functions in each of these three modes (described below) is given.

These parameters are defined such that improper element function in the related mode is approached as the parameter value approaches one. A circuit designer can use these parameter values to gain some feel for how close to failure his circuit comes when an element operates at the indicated fanout levels; i.e., how close the parameter value is to unity.

An OR/NOR element must operate in the OR/NOR mode. For an element to function properly in the OR/NOR mode, an upstream off output must be at a low enough level to insure that any downstream element(s) to whose control port(s) it is connected will switch to or remain in an OFF state under worst case conditions. Worst case here implies that the highest level off output flow drives the control port(s) requiring the lowest control flow to switch off. To insure that the element acts in the OR/NOR mode, then

$$\frac{(QOSWF1)_{MAX}}{K} < (QCSWOFFMIN)_{MIN}.$$

QOSWF1 is the highest flow level of an off output at PO = $PCSWOFF_{MIN}$. This parameter has a value calculated and listed for each type 3 off curve. QCSWOFFMIN is the lowest flow level into a control port that insures the switch of an element to the off state. It has a value listed in the standard printout for each type 2 curve. The K is the integer value of fanout for which the OR/NOR parameter has been calculated.

The parameter value listed for the OR/NOR mode is given by

$$\frac{(QOSWF1)_{MAX}}{K(QCSWOFFMIN)_{MIN}}$$

The value of this ratio for proper OR/NOR function is less than one if $QCSWOFFMIN_{MIN}$ is positive and greater than one if it is negative.

A flip flop must operate in both the FLIP FLOP(OFF) and FLIP FLOP(ON) modes. The FLIP FLOP(OFF) mode of operation means that an upstream

off output must be at a high enough level to insure that any downstream element(s) to whose control port(s) it is connected will remain in an on state (if initially on) when the upstream output is turned off under worst-case conditions; i.e., when the lowest level off output flow drives the control port(s) allowing the highest flow when they switch off.

If the element acts in the FLIP FLOP(OFF) mode, then

$$\frac{(QOSWF2)_{MIN}}{K} > (QCSWOFFMAX)_{MAX}.$$

QOSWF2 is the lowest flow level of an off output at $PO = PCSWOFF_{MAX}$, calculated from the type 3 curve. QCSWOFFMAX is the highest flow level into a control port which still allows an element to switch to the off state and is calculated using the type 2 curve. Again, K is the associated fanout.

The parameter value listed is given by

$$\frac{(QOSWF2)_{MIN}}{K(QCSWOFFMAX)_{MAX}}.$$

For proper FLIP FLOP(OFF) function, the value of this ratio should be greater than one if $QCSWOFFMAX_{MAX}$ is positive and less than one if it is negative.

The FLIP FLOP(ON) mode refers to an upstream off output that is at a level low enough to insure that, for worst case conditions, any downstream element(s) to whose control port(s) it is connected will not be switched to an on state. Worst case means that the highest level off output flow drives the control port(s) requiring the lowest flow to switch on. This is given by

$$\frac{(QOSWF3)_{MAX}}{K} < (QCSWONMIN)_{MIN}.$$

QOSWF3 is the highest off output flow level at $PO = PCSWON_{MIN}$, K is the fanout and QCSWONMIN is the lowest control flow needed to switch an element to the on state.

The parameter value is given by

$$\frac{(QOSWF3)_{MAX}}{K(QCSWONMIN)_{MIN}}$$

and must be less than one for $(QCSWONMIN)_{MIN}$ positive and greater than one when it is negative.

Some obvious relationships can be seen among the three parameters defined above. If, for a given fanout, an element functions in the OR/NOR mode, it must also function in the FLIP FLOP(ON) mode. However, an element that functions in the FLIP FLOP(ON) mode does not necessarily function in the OR/NOR mode.

The OR/NOR and FLIP FLOP(OFF) modes are mutually exclusive at any given fanout. However, while an element cannot function as both OR/NOR and FLIP FLOP(OFF) at a given fanout, it may not function as either.

8.4 <u>Flow Recovery</u>

Flow Recovery = $\overline{QO(PO=0)ON/QS}$

where QS is obtained in one of five ways:

(a) If QS was recorded in the same file as the type 3 curve (QO_i vs PO_i), and the number of values saved was no greater than the internal memory storage capability assigned to QS by the system (section 2.1.1(c), then the mean value of QS is used.

(b) If QS was recorded in the same file as the type 3 curve but the number of values saved was greater than the internal memory storage capability, then the first value of QS is used.

(c) If PS was recorded in the same file as the type 3 curve, but QS was not, and the number of PS values saved does not exceed the internal memory storage capability (as above), then the mean value of PS is used to obtain $QS = QS[f_1\ (PS_{mean})]^0$.

(d) If PS was recorded but QS was not and the number of PS values saved exceeds internal memory capability, then the first value of PS is used to obtain: $QS = QS[f_1\ (PS_{Initial})]^0$.

(e) If neither QS nor PS were recorded, then QS = QS TYPICAL = QS$[f_1$(PS TYPICAL)$]^0$ is used.

The values of QO(PO=0)ON appear in the standard printout for each type 3 on curve. Note that if PO≠0, the minimum PO value is used to obtain this value of QO.

8.5 Pressure Recovery

Pressure Recovery = $\overline{\text{POMAX/PS}}$

where POMAX = PO $[f_{3_{ON}}$ (QO $\geq$ 0)$]^0$, and where PS is defined in one of three ways.

(a) The mean value of PS, if it were recorded in the same file as the type 3 curve and if the number of values saved does not exceed internal memory storage capability (section 2.1.1, c).

(b) The initial value of PS, if it were recorded in the same file as the type 3 curve and if the number of values saved exceeds internal memory storage capability.

(c) PS TYPICAL, if PS were not recorded.

Values of POMAX and PS are listed on the standard printout for each type 3 on curve.

8.6 Flow Gain

Flow Gain = [(QOSWON-AVG)-(QOOFF-AVG)]/[(QCSW-AVG) - (QC(PC=0)AVG)]

when PO is the dependent parameter of a type 5 curve. When QO is the dependent parameter specified for curve 5, flow gain is given by

Flow Gain = $[\overline{\text{QO(PCSWON-I) - QO(PC=0)ON}}]$/[(QCSW-AVG)- (QC(PC=0)AVG)].

The four parameters used to calculate flow gain in the first equation are single-valued and are listed toward the bottom of the standard printout. Values for QO(PCSWON-I) and QO(PC=0)ON are listed in the standard printout for each type 5 curve.

Note that if PO≠0 or PC≠0, the minimum values of PO and PC are used to obtain QO(PO=0)OFF and QC(PC=0) (used to compute the values of QOOFF-AVG and QC(PC=0)AVG, see table 8.2), respectively.

If both PO and QO are specified as the dependent parameter of type 5 (PC_i vs QO_j or PO_j) curves, the value of flow gain is a weighted average of the two equations.

8.7 Power Gain

Power Gain = [(QOPOON-AVG)-(QOPOOFF-AVG)]/[(QCSW-AVG)(PCSWON-AVG)]

The four parameters on the R.H.S. of the above equation are the average values of other parameters listed on the standard printout (see table 8.2).

8.8 Pressure Gain

When PO is the dependent parameter for the type 5 curve (PC_i vs PO_j), pressure gain is defined as

Pressure Gain = $\overline{|[PO(PCSWON\text{-}I)-PO(PC=0)ON]/(PCSWON\text{-}AVG)|}$.

When QO is the dependent parameter specified for the type 5 curve, (PC_i vs QO_j) pressure gain is given by

Pressure Gain = $[\overline{POSWON} - \overline{POF}]/(PCSWON\text{-}AVG)$.

8.9 Hysteresis

Hysteresis = $PCSWON_{MAX} - PCSWOFF_{MIN}$

The parameters on the R.H.S. of the above equation are defined in table 8.2 and illustrated in figure 4.

9. Running the FLUID Program

This section describes the control cards needed to run a FLUID program on the HDL 7094 computer.

Column Number

```
1             1
              6

$JOB
$PAUSE        MOUNT TAPE FLUID (96) ON A5
$EXECUTE      USER
$FLUID
$DATA
           [command program deck]
              [data cards if any]
```

```
$EOF
$IBSYS
$REMOVE      SYSCK1
$*           NEXT 3 CARDS INCLUDED IF PUNCHING WAS REQUESTED
$ATTACH      B7
$AS          SYSUT6
$REMOVE      SYSUT6
$*           NEXT 3 CARDS INCLUDED IF UNIT 10 WAS USED
$ATTACH      B6
$AS          SYSUT7
$REMOVE      SYSUT7
$*           NEXT 3 CARDS INCLUDED IF UNIT 9 WAS USED
$ATTACH      A6
$AS          SYSUT8
$REMOVE      SYSUT8
$*           NEXT CARD INCLUDED IF TAPE INPUT OPTION WAS USED
$REMOVE      SYSCK2
$RESTORE
$EOF
```

A modified version of the control cards is given in Appendix B if the FLUID tape is not under the USER SYSTEM.

The user should remember that logical unit 10 is used whenever there is a normal RETAPE command. However, unit 10 may also be used on a TAPEWT(10) command. Also, logical unit 9 is used whenever there is a normal TAPEWT command. However, unit 9 may also be on a RETAPE (9) command.

9.1 HDL Computer Job Slip Preparation

In addition to the normal information needed for the job slip, the following should be included when appropriate:

(a) Circle tape drive A5 for input and include the name FLUID along with its tape number 96.

(b) If PUNCH was used (or the punch feature on PLOT), circle drive B7 as output and indicate "punch tape" under tape title. Under the punch section, write B7 and indicate the number of cards to be punched in the CARDS/FILE slot. Give the number of files as 1 and the type as BCD. If it is desirable to be able to visually read the cards, indicate in the special instruction block that the cards should be interpreted.

(c) If logical unit 10 was used with a normal RETAPE option, TAPEWT(10) or the TAPE(10) feature on PLOT, circle drive B6 as input (for RETAPE) or output (for TAPEWT or TAPE) or both. Indicate a tape serial number and title if the tape was previously saved or is to be newly created and saved. If no information is to be permanently saved, just use some title such as "scratch tape."

If the tape is to be created, include a tape label card (Form 921) that will reserve a tape for the user under the proposed title and will also assign a serial number for future use.

(d) If logical unit 9 was used with a RETAPE(9) option, a normal TAPEWT or the TAPE(9) feature on PLOT, circle drive A6 and include information as indicated by (c) above.

(e) If TAPE was used, circle drive B5 as input and indicate tape serial number and title.

(f) If either PLOT or STDPLT was used, circle B9 as output and indicate plot tape under tape title. If desirable, indicate 12" paper for plot in special instruction block.

(g) If SPILL feature is used (section 5.7.1), indicate in special instruction block the serial numbers of the back-up tapes.

(h) If MOUNT feature is used (section 5.7.1), indicate in special instruction block the serial numbers of any tapes that are not to be mounted initially.

9.2 System Requirements

The program is too large to fit into the computer memory without use of the DISK/IBSYS overlay feature. The program requires the standard I/O tape drives, logical units 5 and 6. In addition, six other tape drives may be used.

(a) A5 - FLUID program resides on tape (SYSCK1 - logical 13).
(b) B5 - BCD input tape for TAPE option (SYSCK2 - logical 14).
(c) A6 - Binary I/O tape for TAPEWT (or RETAPE) option (logical 9).
(d) B6 - Binary I/O tape for RETAPE (or TAPEWT) option (logical 10).
(e) B7 - BCD output tape for PUNCH option (logical 12).
(f) B9 - Output tape for plotting (SYSUT9).

The system also makes use of a 1301-2 disk, using the first 6400 tracks (466 words/track) of MODULE 0(ED00/0). The plotting is done on a Calcomp 663/760 30" drum plotter, where the Calcomp plot routines are in the system program library.

9.3 Error Messages

The following is a list of error messages (along with brief explanations) that are generated by the system when an error occurs. If any error has occurred, the system will stop after scanning all the commands.

(1) ERROR IN INPUT CARD

This message results if there is an error interpreting an input card, and appears after the card is read. Other input cards will be checked for errors also; however, subsequent errors could result from earlier card error. Program will be stopped after reading input card list.

(2) TOO MANY CHANNEL POINTS TO STORE

Variable or channel ID values require more than 24 tracks for temporary storage. Choose larger DELTX value.

(3) TOO MANY POINTS TO CALIBRATE FOR CHANNEL ID

In the calibration file, data must be small enough so that disk storage is not required (see section 1.1(c)).

(4) UNDEFINED NAME ON VARIABLE CARD name

A name that has not been previously defined has been used in a variable expression.

(5) BAD POINT AT SCAN scan number = 16 character channel recording

If the CHINP TAPE option is used, this message appears for each bad (or unreadable) channel recording. (This message does not stop the program).

(6) RUN STOPPED BECAUSE OF EXCESSIVE BAD CHANNEL VALUES

If the CHINP TAPE option is used, this message appears when the number of bad channel recordings (see error 5) exceeds a specified limit (see section 5.1(c)).

(7) NO CHANNEL NAMES FOR STANDARD PLOT

One of the channel ID or variable names that should be on the standard plot was never defined or has no values.

(8) UNEQUAL NUMBER OF P'S and Q'S

The indices of PC and QC or of PO and QO ID's do not match in standard curve types 2 or 3 (see section 7.5 (e)).

(9) PROGRAM STOP FROM EXCESS TAPE OUTPUT

There is no more room for output on the TAPEWT unit. Use the SPILL feature, if desirable (see section 5.7.1 (b)).

(10) NO POINTS TO CALIBRATE FOR CHANNEL ID name

CHINP TAPE option was used, and a calibration file contained less than three independent points. Unreadable values are not counted. This message stops program execution (see section 2.1.4 (b)).

(11) ID TABLE EXCEEDS 20

There are more than 20 ID's defined at one time.

(12) CONSTANT TABLE EXCEEDS 60

There are more than 60 constants defined at one time.

(13) VAR TABLE EXCEEDS 30.

There are more than 30 variables defined at one time.

(14) SCAN TABLE EXCEEDS 50.

More than 50 manual entry numbers are listed on SCAN statements.

(15) PLOT TABLE EXCEEDS 20.

More than 20 plots are defined at one time.

(16) LIST OF SKIPPED FILES EXCEEDED.

SKPFLE statements contain a list of more than 20 files to be skipped.

10. Examples of Fluid Program

This section illustrates the use of a few of the major features available in FLUID. In these examples, the type and format of data to be handled by the program, the required output from the program command statements that generate that output, and finally, some of the output are listed.

10.1 Generation of GFCG Digital Fluidic Component Fact Sheet from Fortran Data

In this example, data has been gathered on a number of identical OR/NOR elements. The testing consisted of varying the pressure level at various ports under the following conditions:

(a) Sweep PS with controls and outputs blocked.

Next six tests done at PS = 45 kPa with all unspecified ports open.

(b) Sweep PC1
(c) Sweep PC7
(d) Sweep PO2
(e) Sweep PO1

Next two tests done at PC7 = 4 kPa (this turns element ON).

(f) Sweep PO2
(g) Sweep PO1

Next six tests done at PS = 45 kPa with all unspecified ports blocked.

(h) Sweep PC1
(i) Sweep PC7
(j) Sweep PO2
(k) Sweep PO1

Next two tests done at PC7 = 4 kPa (this turns element ON).

(l) Sweep PO2
(m) Sweep PO1

The above series of tests provide both open and closed port characteristic data on a single OR/NOR element with four controls (C1, C3, C5, C7) and two outputs (O1, O2). To reduce testing and data reduction time, the pressure is swept only at control ports C1 and C7. The two output ports are swept while both ON and OFF. There are a total of 13 pressure sweeps at the various ports of each element.

The output required from these data consists primarily of the parameter values and curves used with the GFCG Digital Fluidic Component Fact Sheet. Also, the processed data are to be stored in their reduced form on a magnetic tape for possible use at a later time. The program also provides a system identifier table for each command file.

The input data are in fortran format on a magnetic tape. A total of five elements were tested. The list of command statements required to reduce these data and provide the above output is shown in figure 5.

There are four title statements used at all times. Title 1 states which element is being tested, where the data came from, the environmental test conditions, and on what date the tests were conducted. Title 2 specifies the test element's load condition. Title 3 indicates the type of test performed. Title 4 lists program input and output tapes used.

Other points of interest are that the data have already been calibrated, although the flow parameters are converted from standard liters per second to standard cubic centimeters per second. The use of the DIFDEL statement is illustrated with PC1 (see figure 5, command statements 6 and 20).

```
FILE  LENGTH(9,65)=354.
TITLE1NO. 1 CORNING DR/NOR DTB REEL 07 7000 FT. ALTITUDE  25 OCT 73
TITLE4 UNIT 11 -       'FORTRAN DATA 7',UNIT  9 -1255 'REDUCED DATA 1'
GENID DIMEN=KPA
ID     PS/
ID      PC1/,DELTX=1.
ID     PC3/
ID     PC5/
ID      PC7/
ID     PO1/
ID      PO2/
GENID    DIMEN=CCPS
ID      QS/
ID      QC1/
ID      QC3/
ID     QC5/
ID     QC7/
ID     QO1/
ID     QO2/
DIFDEL   PC1(0.,5.,.1)
CALIB (QS),0.,1000.,(QC1),0.,1000.,(QC3),0.,1000.,(QC5),0.,1000.
CALIB (QC7),0.,1000.,(QO1),0.,-1000.,(QO2),0.,-1000.
TAPEWT (9) 65,PS,PC1,PC3,PC5,PC7,PO1,PO2,QS,QC1,QC3,QC5,QC7,QO1,QO2
BLOCK 8
TITLE2  CONTROL PORTS OPEN, OUTPUT PORTS BLOCKED
BLOCK 2
CHINP  TAPE/1,14,(14E12.5)
ENDBLK
STDPRT0.0254,2.0,20.0,70.0,45.0
KEEP    ALL
BLOCK 3
STDPLT1,4(PS,PO1,PO2)
TITLE3SWEEP PS
END
ENDBLK
RESET CHINP,TAPEWT
TAPEWT(10)PS,QS,PO1,PO2
END
BLOCK 4
RESET TAPEWT
COPY  2
TAPEWT(9)PS,PC1,PC3,PC5,PC7,PO1,PO2,QS,QC1,QC3,QC5,QC7,QO1,QO2
ENDBLK
TITLE3SWEEP PC1
TITLE2  PORTS OPEN
STDPLT2(PC1,QC1),5(PC1,QO1,QO2)
END
TITLE3SWEEP PC7
STDPLT2(PC7,QC7),5(PC7,QO1,QO2)
END
```

Figure 5. List of Command Statements for First Example

```
BLOCK 6
TITLE3SWEEP PO2 (ON)
STDPLT3N(PO2,QO2)
END
TITLE3SWEEP PO1 (OFF)
STDPLT3F(PO1,QO1)
END
TITLE3SWEEP PO2 (OFF)
STDPLT3F(PO2,QO2)
END
TITLE3SWEEP PO1 (ON)
STDPLT3N(PO1,QO1)
END
RESET TAPEWT,STDPLT,TITLE(3),CHINP
END
ENDBLK
REWIND 10
CHINP RETAPE (10)
COPY  3
COPY  2
COPY  4
TITLE2 PORTS BLOCKED
TITLE3 SWEEP PC1
STDPLT2(PC1,QC1),5(PC1,PO1,PO2)
END
TITLE3 SWEEP PC7
STDPLT2(PC7,QC7),5(PC7,PO1,PO2)
END
TAPEWT(9)PS,PC1,PC3,PC5,PC7,PO1,PO2,QS,QC1,QC3,QC5,QC7,QO1,QO2
COPY  6
ENDBLK
TITLE1NO. 2 CORNING OR/NOR DTB REEL 07 7000 FT. ALTITUDE  25 OCT 73
COPY  8
TITLE1NO. 3 CORNING OR/NOR DTB REEL 07 7000 FT. ALTITUDE  25 OCT 73
COPY  8
TITLE1NO. 4 CORNING OR/NOR DTB REEL 07 7000 FT. ALTITUDE  25 OCT 73
COPY  8
TITLE1NO. 5 CORNING OR/NOR DTB REEL 07 7000 FT. ALTITUDE  25 OCT 73
COPY  8
STOP
```

Figure 5. (cont)

Two sets of standard plots and printout sheets are desired for each element (one for open, one for closed port load conditions). Since PS is swept only once, it is necessary to use this same curve twice in order to make the second set of standard plots complete. This is accomplished by use of a "scratch tape" on computer drive 10 (see section 4.4 (b)). The appropriate command statements are listed in figure 5 as numbers 30 and 36 through 43.

Samples of the program output are shown in figures 6 through 8. Figure 6 shows a typical System Identifier Table. The standard printout sheet for open port characteristics is shown in figure 7. The corresponding set of standard plots is in figure 8.

10.2 Use of Standard Tape Input

This example illustrates the use of calibration data that are recorded on a standard tape. Files one, two, and three contain these data. Files four and six contain element performance data.

The first seven ID's represent the output of pressure transducers that directly measure the pressure at the power, control, and output ports of the flip flop being tested. The next seven ID's represent the output of pressure transducers that measure the pressure drop across the ports of flow meters that are connected to the various ports of the flip flop. The relationship between this pressure drop and volume flow in liters per minute is expressed by the first seven VAR commands. The next seven VAR commands convert volume flow in liters per minute to standard volume flow in liters per second.

The output from the program is in the form of plots. Title commands are used to label the plots. Use of the common scale feature is illustrated in the first plot command.

Figure 9 shows the command statements used in this program. Figures 10 and 11 show the two plots based on data from files four and six, respectively.

10.3 Generation of Graph from Standard Tape Input

This example illustrates the method used to generate a family of curves from a number of different data files onto a single graph that has axis limits compatible with all the data contained in those files.

The input data are on a RETAPE and are contained in 24 data files. The first and fourteenth files do not contain useful information. The only required system output is one graph.

SYSTEM IDENTIFIER TABLE

NO. 1 CORNING OR/NOR DTB REEL 07 7000 FT. ALTITUDE 25 OCT 73
PORTS OPEN
SWEEP PC7
UNIT 11 - 'FORTRAN DATA 7',UNIT 9 -1255 'REDUCED DATA 1'

OUTPUT IS FOR INPUT FILE NUMBER 6 ON UNIT 14
THIS DATA FILE HAS TAPE OUTPUT ON FILE NUMBER 68 ON UNIT 7
THE LENGTH RANGE FOR TAPE FILE OUTPUT IS 367.9- 377.0 FEET
THE NUMBER OF SCANS IS 208

NAME	/DIMENS	MIN	MAX	MEAN(SUM/N)	MEDIAN	ST.DEV.	NO.POINTS	PUNCH/TAPE/PLOT
ID-VALUES								
PS	/KPA	4.45690E 01	4.59370E 01	4.48152E 01	4.48380E 01	3.87136E-01	208	N/Y/N
PC1	/KPA	-5.15760E-01	5.68430E-01	-8.49678E-02	0.00000E-39	2.99466E-01	117	N/Y/N
PC3	/KPA	-5.74090E-01	6.37880E-01	-1.47204E-02	0.00000E-39	2.21985E-01	193	N/Y/N
PC5	/KPA	-5.38870E-01	7.02750E-01	-9.12232E-02	-1.27770E-01	2.59715E-01	153	N/Y/N
PC7	/KPA	-1.27160E 01	2.31610E 01	5.52120E 00	5.73350E 00	1.04801E 01	196	N/Y/N
P01	/KPA	-5.07390E 00	5.25400E-01	-2.06409E-01	-1.30100E-01	4.08464E-01	177	N/Y/N
P02	/KPA	-9.24460E-01	3.87080E 00	-2.35279E-01	-2.76490E-01	4.46308E-01	202	N/Y/N
QS	/CCPS	2.64680E 01	2.85110E 01	2.76602E 01	2.79750E 01	5.68528E-01	98	N/Y/N
QC1	/CCPS	-1.94240E 00	2.25300E 00	-3.50374E-01	-4.17460E-01	6.48967E-01	201	N/Y/N
QC3	/CCPS	0.00000E-39	0.00000E-39	0.00000E-39	0.00000E-39	0.00000E-39	3	N/Y/N
QC5	/CCPS	-1.05600E 00	3.08610E 00	1.62855E-01	-1.45160E-01	6.30502E-01	157	N/Y/N
QC7	/CCPS	-1.42210E 01	1.78390E 01	4.22141E 00	8.41280E 00	1.10909E 01	194	N/Y/N
Q01	/CCPS	-1.14900E 00	4.73830E 01	2.72747E 01	4.44560E 01	2.12118E 01	182	N/Y/N
Q02	/CCPS	5.53880E 00	4.17700E 01	2.19447E 01	9.08070E 00	1.64296E 01	207	N/Y/N
COMMON-VAL								

Figure 6. System Identifier Table from Typical File in First Example

```
NO. 1 CORNING OR/NOR DTB REEL 07 7000 FT. ALTITUDE  25 OCT 73
 PORTS OPEN

 UNIT 11 -        'FORTRAN DATA 7',UNIT  9 -1255 'REDUCED DATA 1'
STANDARD PRINTOUT

1.  NOZZLE WIDTH=                  0.025400          7.  PRESSURE RECOVERY=     0.229056
2.  ASPECT RATIO=                  2.000000          8.  FLOW GAIN=             4.655034
3A. SUPPLY PRESSURE(RANGE)=       20.000000          9.  POWER GAIN=            7.260721
                     TO           70.000000          10. PRESSURE GAIN=         2.144937
3B. SUPPLY PRESSURE(TYPICAL)=     45.000000          11. HYSTERESIS=            3.462300
4.  POWER CONSUMPTION(WATTS)=  8.833980E-01
5.  FANOUT=                        4.000000
6.  FLOW RECOVERY=                 1.511558

SYSTEM VARIABLES
  PRESS GAIN  PO(PC=0)ON  MAXPO(PC-I)  MINPO(PC-I) PO(PCSWON-I) PO(PCSWON-D)     GAINON      GAINOFF       PCSWON       PCSWOFF
              QO          QO           QO          QO           QO
   9.334804    -3.299923   47.383000    -9.000800   44.456000    45.344928    10.449149    12.403208     5.115900     1.653600
   6.533611    42.505998   43.000999     3.866700    9.080700     7.706404     6.795500     9.375154     5.115900     1.653600
  11.996090     2.257940   47.383000    -1.149000   43.797999    44.772936    12.979958    25.120752     3.462800     1.873300
   9.391562    40.963003   41.770000     5.538800    8.441900     7.257575     9.624610    20.953397     3.462800     1.873300

PO(PCSWOFFD)  POONLIM(20)  POONLIM(33)  POOFFLIM(20)  MAXPO(PC-D)  MINPO(PC-D)
QO            QO           QO           QO            QO           QO
    2.401300    33.764639    28.588400     3.902906    47.154000    -6.457600
   40.166000    15.189920    16.911466    35.120481    41.974000     3.866700
    4.843500    34.808599    31.205667     8.035387    47.383000    -1.149000
   40.563000    15.107520    17.615866    34.867515    41.770000     6.416100

        QC(PC=0)          SWONMAX          QCSWOFFMAX        QCSWONMIN        QCSWOFFMIN
     -0.450491816       8.754499912       4.069400012       8.499299884      3.593899995
     -1.232399970       6.237283707       4.313300014       6.236199975      4.046665847

   FLOW REC.   QO(PO=0)ON  QO(PO=0)OFF      QOSWON     QOPOMAXON   QOPOMAXOFF        POMAX   PRESS. REC.
   1.464867    41.215745                 35.605192    244.410051                  11.195798     0.251546
                           -0.448100                                -0.000000
                            4.840500                                 0.000000
   1.558249    43.582666                 35.311226    222.490641                   9.284699     0.206565

        QS           PS          POF        POSWON       QOSWF1       QOSWF2       QOSWF3
  28.136167    44.508300                 10.382500
                            0.031942                  -15.055239   -16.632016   -23.013997
                            0.391989                  -12.056535   -13.224327   -19.914573
  27.969002    44.948000                  8.442200

 QS TYPICAL  PCSWON-AVG  QC(PC=0)AVG    QCSW-AVG    QOOFF-AVG   QOSWON-AVG  QOPOON-AVG  QOPOOFF-AVG
  28.349959    4.289350    -0.841446    7.495892     2.196200    35.458209  233.450346     0.000000

LOGIC PARAMETERS FOR FANOUT UP TO      4.033
                 FANOUT             OR/NOR       FLIP FLOP(OFF)      FLIP FLOP(ON)
                     1               -3.35               -3.86              -3.19
                     2               -1.68               -1.93              -1.60
                     3               -1.12               -1.29              -1.06
                     4               -0.84               -0.96              -0.80
OPERATIVE FANOUTS ARE              1 TO   4            0 TO   0           1 TO   4
```

Figure 7. Standard Printout for Open Port Characteristics in First Example

BEST AVAILABLE COPY

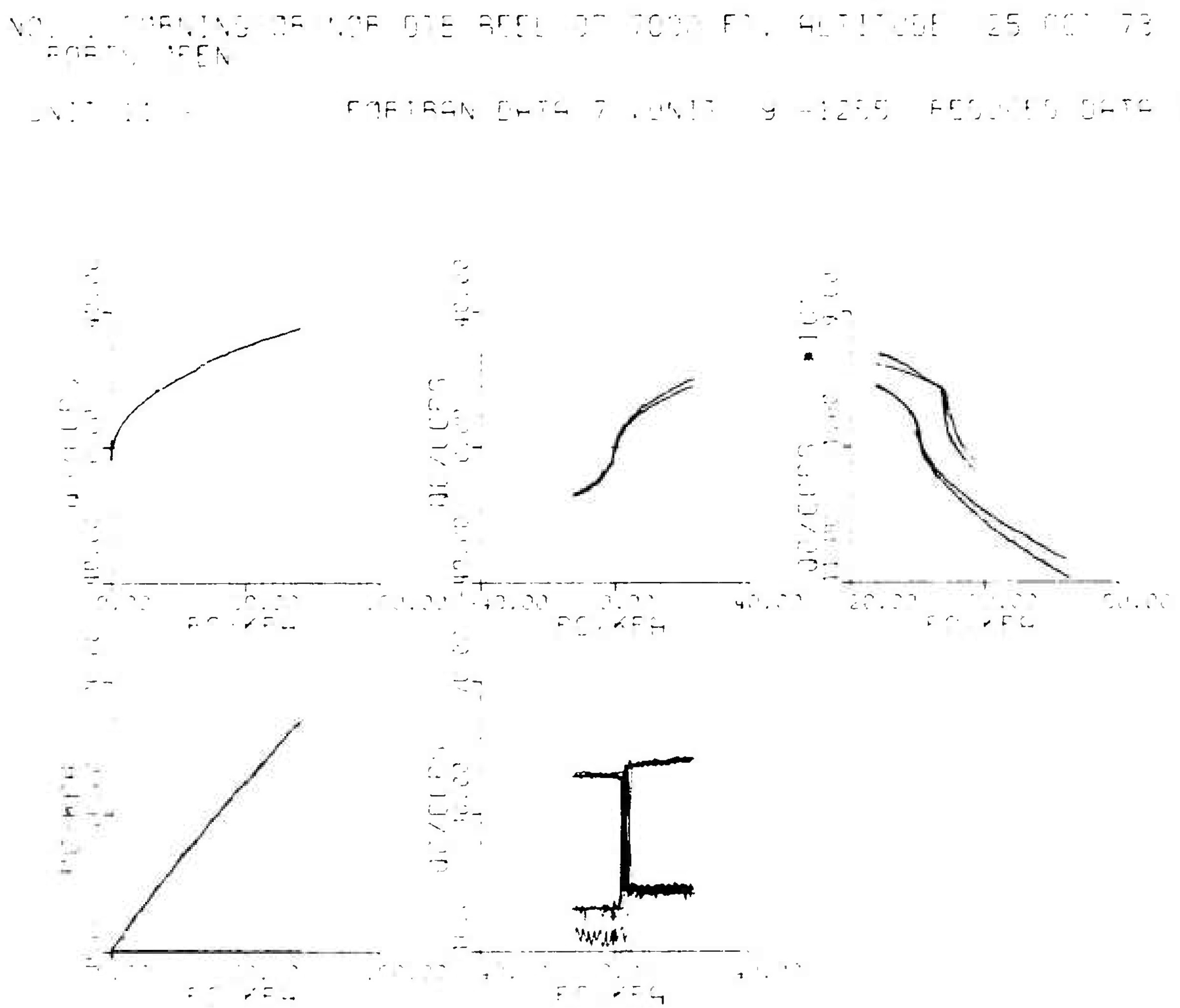

Figure 8. Standard Plots for Open Port Characteristics in First Example

```
SKPFLE 14(5)
ID     PS/,0
ID     PC1/,1
ID     PC2/,2
ID     PC3/,3
ID     PC4/,4
ID     PO1/,5
ID     PO2/,6
GENID DIMEN=INH2O,DELTX=0.1
ID     TQS/,7
ID     TQC1/,8
ID     TQC2/,9
ID     TQC3/,10
ID     TQC4/,11
ID     TQO1/,12
ID     TQO2/,13
CONST C1=10.0,C2=60.,C3=101.32
VAR    VQS/LPM=TQS*(.364436+TQS*(-.0011997))
VAR    VQC1/LPM=TQC1*(.0928197+TQC1*(.0011314))
VAR    VQC2/LPM=TQC2*(.0086168+TQC2*(-.0001691))
VAR    VQC3/LPM=TQC3*(.0084155+TQC3*(.0001989))
VAR    VQC4/LPM=TQC4*(.094906+TQC4*(-.0023273))
VAR    VQO1/LPM=(2.8/C1)*TQO1
VAR    VQO2/LPM=(3.0/C1)*TQO2
VAR    QS/LPS=(VQS/C2)*(PS+C3)/C3
VAR    QC1/LPS=(VQC1/C2)*(PC1+C3)/C3
VAR    QC2/LPS=(VQC2/C2)*(PC2+C3)/C3
VAR    QC3/LPS=(VQC3/C2)*(PC3+C3)/C3
VAR    QC4/LPS=(VQC4/C2)*(PC4+C3)/C3
VAR    QO1/LPS=(VQO1/C2)*(PO1+C3)/C3
VAR    QO2/LPS=(VQO2/C2)*(PO2+C3)/C3
CHINP TAPE*100
END
END
END
TITLE1  POWER IMPEDANCE AND FLOW RECOVERY CURVES
PLOT   MARK(10),(PS,COMMON/QS,QO2)
END
RESET PLOT
TITLE1  NORMALIZED CONTROL IMPEDANCE CURVE
VAR    PC1N=PC1/PS
VAR    QC1N=QC1/QS
PLOT   (PC1N,QC1N)
END
STOP
```

Figure 9. List of Command Statements for Second Example

BEST AVAILABLE COPY

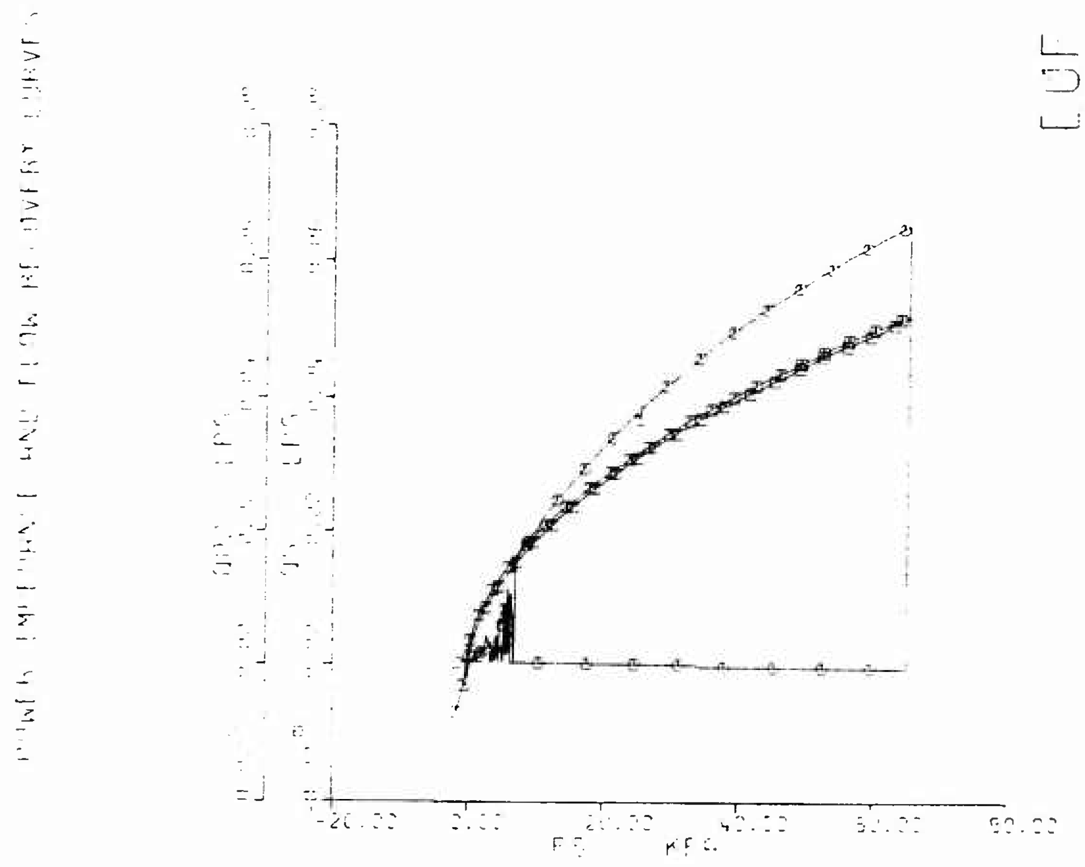

Figure 10. Plot of Data From Data File Four in Second Example

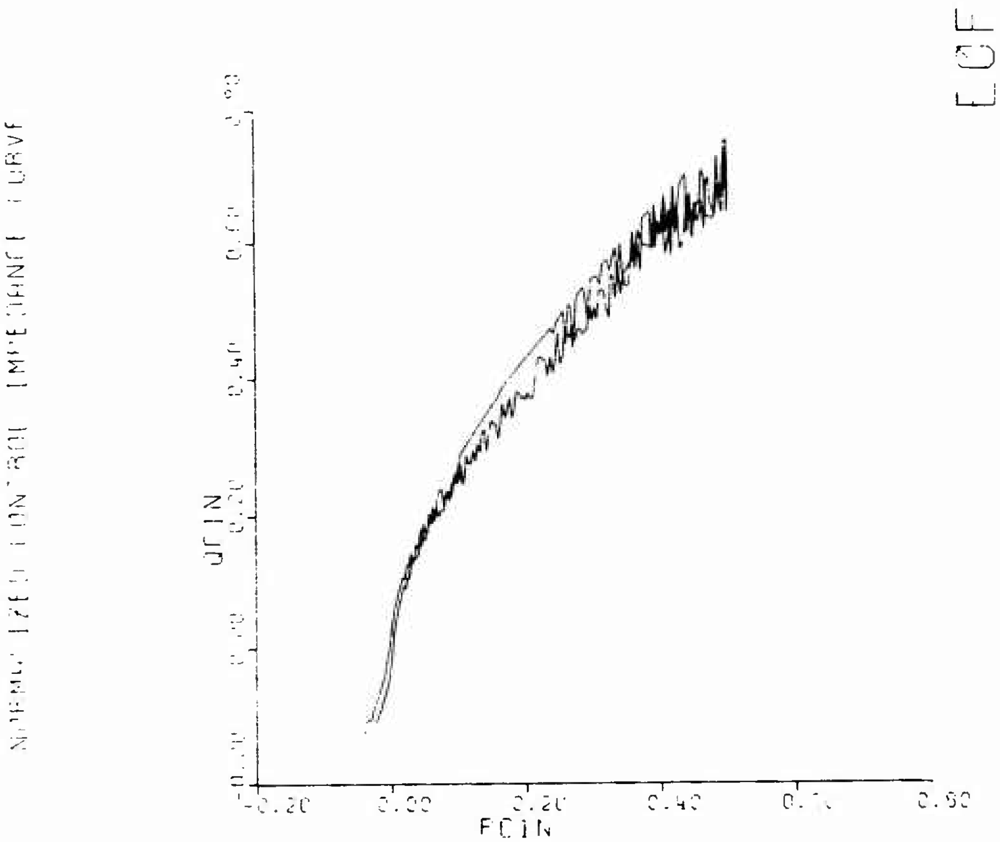

Figure 11. Plot of Data From Data File Six in Second Example

A list of the command statements is shown in figure 12. Figure 13 shows a list of command statements plus System Identifier Table for the first command file. Figure 14 shows the graph generated by the program.

11. SUMMARY

The FLUID system provides a flexible, easy-to-use tool to assist in the evaluation of fluidic devices. Use of the computer permits large amounts of data to be handled quickly and efficiently. It is hoped that this capability will encourage not only more complete data analysis, but also the presentation of fluidic device operating characteristics in an accepted, standard format.

```
TITLE1CONTROL AND OUTPUT CHARACTERISTICS FOR CORNING OR/NOR
TITLE2WITH OPEN PORTS
ID     PC1/
ID     PC7/
ID     PO1/
ID     PO2/
GENID DIMEN = CCPS
ID     QC1/
ID     QC7/
ID     QO1/
ID     QO2/
SKPFLE10(1,14)
CHINP RETAPE
COMMON 1(PC1,PC7,PO1,PO2),2(QC1,QC7,QO1,QO2)
BLOCK 2
BLOCK 1
UPDATE 2/PC1(QC1)
END
UPDATE 2/PC7(QC7)
END
UPDATE 2/PO2(QO2)
END
UPDATE 2/PO1(QO1)
END
UPDATE 2/PO2(QO2)
END
UPDATE 2/PO1(QO1)
END
ENDBLK
TITLE2WITH BLOCKED PORTS
COPY  1
ENDBLK
TITLE1CONTROL AND OUTPUT CHARACTERISTICS FOR CORNING OR/NOR NO.2
COPY  2
RESET CHINP
TITLE2WITH PORTS BOTH OPEN AND BLOCKED
GRAPH 2,8.,8.,(P/KPA,Q/CCPS)
END
STOP
```

Figure 12. List of Command Statements for Third Example

```
TITLE1CONTROL AND OUTPUT CHARACTERISTICS FOR CORNING OR/NOR
TITLE2WITH OPEN PORTS
ID      PC1/
ID      PC7/
ID      PO1/
ID      PO2/
GENID DIMEN = CCPS
ID      QC1/
ID      QC7/
ID      QO1/
ID      QO2/
SKPFLE10(1,14)
CHINP RETAPE
COMMON 1(PC1,PC7,PO1,PO2),2(QC1,QC7,QO1,QO2)
UPDATE 2/PC1(QC1)
END
```

BEST AVAILABLE COPY

SYSTEM IDENTIFIER TABLE

CONTROL AND OUTPUT CHARACTERISTICS FOR CORNING OR/NOR
WITH OPEN PORTS

OUTPUT IS FOR INPUT FILE NUMBER 2 ON UNIT 10
THE NUMBER OF SCANS IS 206

NAME	/DIMENS	MIN	MAX	MEAN(SUM/N)	MEDIAN	ST.DEV.	NO.POINTS	PUNCH/TAPE/PLOT
ID-VALUES								
PC1	/KPA	-1.24540E 01	2.33060E 01	5.49675E 00	4.70250E 00	1.03851E 01	136	N/N/N
PC7	/KPA	2.27450E-01	5.68620E-01	4.07971E-01	3.98030E-01	5.41226E-02	23	N/N/N
PO1	/KPA	-3.89170E-01	5.18900E-01	1.19020E-01	0.00000E-39	2.73256E-01	61	N/N/N
PO2	/KPA	-1.52560E 00	-1.38690E-01	-7.79620E-01	-6.93440E-01	3.83382E-01	55	N/N/N
QC1	/CCPS	-1.72860E 01	2.34900E 01	6.12615E 00	9.55630E 00	1.37268E 01	206	N/N/N
QC7	/CCPS	2.01550E 00	3.31940E 00	2.60014E 00	2.63260E 00	3.10054E-01	113	N/N/N
QO1	/CCPS	-9.08400E 00	5.72790E 01	2.82565E 01	5.34650E 01	2.93688E 01	149	N/N/N
QO2	/CCPS	8.55930E 00	5.03300E 01	2.76668E 01	8.77060E 00	2.03311E 01	122	N/N/N
COMMON-VAL								
1		-0.00000E-20	-0.00000E-20					
2		-1.72860E 01	2.34900E 01					

Figure 13. Command Statements and System Identifier Table From First File of Third Example

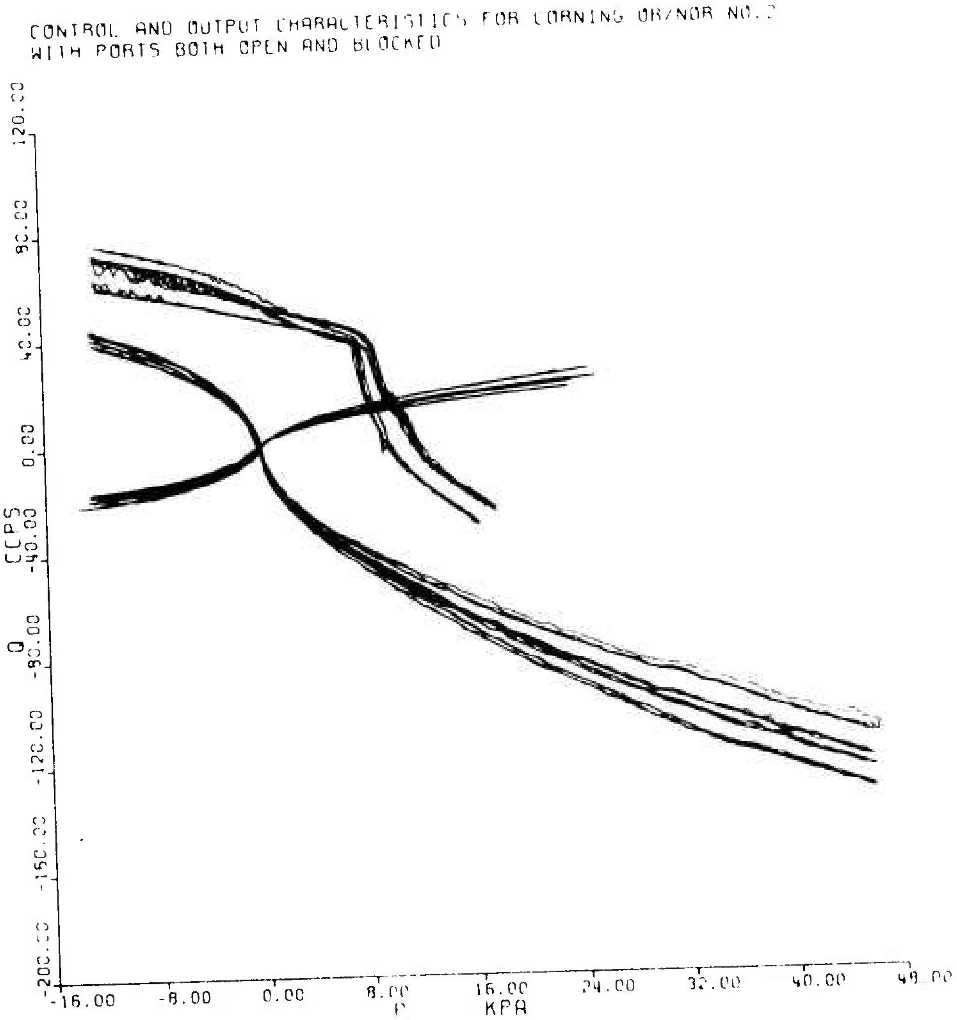

Figure 14. Graph Output From Third Example

Appendix A Card Type Format

The general format for all command cards is placement of the command type left-justified in columns 1-6 and the command field in columns 7-72. In general, blanks are ignored in all command fields except for LABEL and TITLE. There are five characteristics that can be attributed to any command.

(1) Field Form - The field form gives a formal description of the command structure. The following notation is used in the command table (table A-1):

(a) "|" - The quantity to the left or right of the "bar" can be used. (In some cases, the quantities will also be enclosed in braces; i.e., " {" and " }" when the field is not optional.)

Example: NRES|RES means that either NRES or RES can be specified--but not both.

(b) "[" and"]" - Brackets are used to enclose quantities that are optional (as opposed to required) in the command description.

Example: [DELTX = number,] means that it is not necessary to include the DELTX value on the command.

(c) "..." - The quantity to the left of the "," preceding the "..." can be repeated as many times as necessary.

Example: [, channel number,...] means that the channel numbers can be repeated.

(d) "anything" - If a number is underlined, this indicates that it must be represented as a decimal number. If not underlined, the number representation is for an integer.

Example: name = <u>constant</u> for CONST command.

The constant is underlined since it must be a decimal number.

(2) Repeatability - The field form can be repeated any number of times with a "," used as a separator.

Example: The TABLE command can have the name repeated
TABLE P01, P02, P03.

However, the VAR command can have only one field specified and hence is not repeatable.

(3) Continuability - The field form can be continued on the next card by placing a "$" in column 72 on the present card. All commands are continuable except for LIST, *, END, and STOP that have no fields and LABELn and TITLEn where the field is strictly defined as columns 7-72.

(4) Additivity - A new appearance of a command does not erase the old command information. However, for the CALIB, CGDEL, LIMIT, and DIFDEL commands, the appearance of a given identifier that was used previously in the command will erase the old information about the identifier. In the case for the COMMON, UPDATE, GRAPH, and SKPFLE command, the appearance of a block number or unit number that was used previously in the command will erase the old information about that number. In the case of the CONST command, the appearance of a constant identifier defined previously will erase the old value. For the ID and VAR commands, the old definition for an identifier must be reset before the new definition is given.

```
Example:      TABLE     QC1, QC2, PC1, PC2
```

is the same as

```
              TABLE     QC1, QC2
              TABLE     PC1, PC2
```

(5) Stability - The introduction of the command applies not only to the file in which it is defined, but for all succeeding files unless it is reset. All commands exhibit stability except for RESET,*, END, STOP, REWIND, FILE, and the three block commands BLOCK, ENDBLK, and COPY. As a special case, the skip file option for the TAPEWT command is only executed in the file for which the TAPEWT was originally defined.

All the characteristics of the commands have been summarized in the command format table (table A-1). For each command there are seven items of information:

(1) Command type.
(2) Features as defined by 2 through 5 above. If the command has the feature, this fact is indicated by the appearance of the first letter in the feature; e.g., RCAS means the command is repeatable, continuable, additive, and stable.
(3) Section Reference - list of sections in the manual that refer to the command.
(4) Restriction - brief summary of command limitations.
(5) Definition.
(6) Field Form.
(7) Examples - One or more examples separated by //. In addition, each of the seven items listed here is separated by a "//."

Table A-1 Command Format Table

Type	// Features // Section References // Restrictions // Definition // Field Form // Examples
*	// A // 3.3 // none // Command serves as program comment // "comment string" // * THIS IS A COMMENT
BLOCK	// none // 3.5 // none // Command allows definition of repeatable set of commands // block index // BLOCK 12
CALIB	// RCAS // 2.1.4a // none // Command sets calibration coefficients for ID's // (name), A-Coefficient, B-Coefficient [, C-Coefficient]// CALIB (PC1), .04, .8, (QC1), .2, 2.3, -.4

CGDEL	// RCAS // 2.1.5c // 5 manual setting max, 6 ID DELTX per setting //
	Command updates the storage resolution factor DELTX for ID if manual setting is scanned //
	manual setting (name = deltax,...) //
	CGDEL 104436 (PC1 = .03, QC1 = .2), 001431 (PC1 = .4)

CHINP	// CS // 5 // none //
	Command defines the input media for data file //
	TAPE[/ number of files to skip] [* bad point limit] |
	STCARD / number of channels per scan, number of cc cards |
	CARD / number of channels per scan, (format) |
	RETAPE [(tape unit)] [/ number of files to skip] |
	CPUNCH |
	TAPE [/ number of files to skip], number of channels per scan, (format) //
	CHINP TAPE/3*100 // CHINP CARD/10, (8F7.2) //
	CHINP RETAPE (9) / 3

COMMON	// RCAS // 6.3 // 12 common blocks //
	Command defines sets of dependent identifiers with common plot scale factor // block number (name,...) //
	COMMON 1 (PC1, PC2, PC3), 2(QC1, QC3)

CONST	// RCAS // 2.3 // 60 constant maximum // Command defines constant identifiers // name = number // CONST X = 1.2, Y = .004

Table A-1 Command Format Table (continued)

Type	// Features // Section References // Restrictions// Definition // Field Form // Examples
COPY	// none // 3.5 // none // Command produces block command code // block index // COPY 3
CTABLE	// RCAS // 4.6 // none // Command generates table of printed constant values // name // TABLE CON1, CON2
DIFDEL	// RCAS // 2.1.5 b // one set of bounds per ID // command allows new DELTX for ID in specific value range // name (lower bound, upper bound, deltax) DIFDEL PC1(.2,.8,.001), QC1(0.,20.2, .4)
END	// none // 3.1 // none // Command defines end of command file // "empty" // END
ENDBLK	// none // 3.5 // none // Command sets end of command block definition // "empty" // ENDBLK
FILE	// CA // 5.7.1 // none // Command allows definition of tape file characteristics // [COUNT (unit) = file number,] [SPILL (serial number,...),] [LENGTH (unit, file number) = feet,] [MOUNT(unit, file number)] // FILE COUNT (9) = 12, SPILL (12,100), LENGTH (9,6) = 100., MOUNT (14,00007), COUNT(14) = 5
GENID	// CAS // 2.1.5 a // none // Command allows definition of new default ID parameters // [DIMEN = dimension type,][NRES|RES,] [DELTX = number] // GENID DIMEN = PSI, RES, DELTX = .5
GRAPH	// CA // 6.4 // none // Command causes common plot block to be graphed // block number, [MARK(number)], [X-axis length, Y-axis length,] (X - name [/dimension type], Y-name [/dimension type]) // GRAPH 1, 6., 8., (PS/PSI, PC/PSI)
ID	// CAS // 2.1 // 20 name maximum // Command defines device port with channel ID name // NAME [/dimension type][, METER (N,...)] [, DELTX = number] [, NRES|RES] [, channel number, ...] // ID PS/PSI, DELTX = 0.2, RES, 1, 6, 11 // ID V, METER (1,2), 1, 2, 3, 4, 5, 6, 7, 8 // ID QC1

Table A-1 Command Format Table (continued)

Type	// Features // Section References // Restrictions // Definition // Field Form // Examples
KEEP	// RCA // 2.5 // none // Command allows ID data to be saved for the next file // name | ALL // KEEP PC1, PC2 // KEEP ALL
LABELn	// S // 6.2 // 20 label maximum // Command allows label to be assigned to special plot // "label string" // LABEL2 THIS IS LABEL FOR PLOT 2
LIMIT	// RCAS // 2.1.5d // none // Command defines limits of acceptable ID data // name (lower bound, upper bound) // LIMIT PC1 (.2, 120.), QC1 (-.1, 8.4)
LIST	// S // 4.7.2 // none // Command generates time and manual setting printout // "empty" // LIST
PLOT	// CAS // 6.1 // 20 plots, 5 y-names per plot // Command sets up curves to be generated for a given plot // [PUNCH,] [MARK [(frequency)] | NOMARK,] [X-axis, Y-axis,] {([SCALE,] name, [lower limit, upper limit, STD|NSTD], . . .), [, ([SCALE,] name, [lower limit, upper limit, STD |NSTD], ...)]} | {(x-name, COMMON{/ |*| -} {number [,name,...]}| {[SCALE, {STD} | {NSTD}, lower bound, upper bound,] name, ...} }// PLOT (X,Y,Z) // PLOT (X,Y), (W,V) // PLOT MARK (5), 4., 4., (SCALE, X, .1, .5, STD, SCALE, Y, .02, 5., NSTD, Z) // PLOT 5., 9., (X, COMMON /4) // PLOT (X, COMMON / Y, Z)
PUNCH	// RCAS // 4.3 // 7 names with bounds // Command sets up list of identifiers whose values are to be punched // name [(lower limit, upper limit)] // PUNCH PC1(.4, 1.2), QC1, PS(0., 15.)

Table A-1 Command Format Table (continued)

Type	// Features // Section References // Restrictions // Definition // Field Form // Examples
RESET	// RCA // 3.4 // none // Command resets information created on other command types // card type [(number ⎱ name [.], ...)] // RESET TABLE, LIST // RESET LABEL (1,3), ID(ALL), VAR(X), TABLE
REWIND	// none // 5.7.2 // none // Command rewinds tape unit // tape unit // REWIND 14
SAVE	// CAS // 4.7.1 // none // Command indicates that time and/or manual settings are to be saved // [MANUAL [(resolution)],] [TIME [(resolution)]] // SAVE MANUAL, TIME (10.)
SCAN	// RCAS // 4.5 // 50 settings max // Command gets final scan numbers for corresponding manual settings // manual setting // SCAN 148248, 148249, 148250
SKPFLE	// RCAS // 5.7.3 // 20 File number maximum per unit // Command saves file numbers to be skipped for a given logical tape unit // unit (file number, ...) // SKPFLF 9(1,4,8), 14(2,6,16,22)
STDPLT	// RC // 7 // none // Command generates data for standard plot // number [N ⎱ F] [(name,...)] // STDPLT 2(PC1,QC1), 5(PC1, P03, P04), 1 // STDPLT 3N(P01, Q01)
STDPRT	// RCS // 8 // none // Command stores five standard print parameters // number // STDPRT 0.0254, 2.0, 20.0, 70.0, 45.0
STOP	// none // 3.1 // none // Command defines end of program // "empty" // STOP

Table A-1 Command Format Table (continued)

Type	// Features // Section References // Restrictions // Definition // Field Form // Examples
TABLE	// RCAS // 4.2 // none // Command generates table of printed identifier values // name // TABLE PC1,X,PC2
TAPEWT	// RCAS // 4.4 // 7 names with bounds // Commands sets up list of identifiers whose values are to be written onto tape // [(tape unit)] [number of files to skip,] name [(lower limit, upper limit)] // TAPEWT (10)5,X,Y(.1, .8) // TAPEWT PC1, PC2
TITLEn	// S // 3.3 // 5 title cards // Command defines title to appear on print and plot output // "title string" // TITLE2 THIS IS THE SECOND TITLE CARD
UPDATE	// RCAS // 6.3.2 // none // Command allows common block information to be updated without plotting // block number [/name][(name, ...)] // UPDATE 1, 2 (PC1, PC2), 3/PS
VAR	// CAS // 2.2 // 30 identifier max, 4 unique identifier names in expression // Command defines expression for variable identifier // name [/ dimension type] = arithmetic expression // VAR X/PSI = PC1-.4 // VAR S = SWITCH (P, 0., 0., PS)

APPENDIX B List of Control Cards

If FLUID is not running under the USER system, the following control cards replace $EXECUTE USER and $FLUID

```
$EXECUTE        IBJOB
$IBJOB          NOMAP
$IEDIT          SYSCK1,SCHF1
$IBLDR  DAT.
$IBLDR  FLUID
$IBLDR  .INPS
$IBLDR  ISRCH.
$IBLDR  ISRCK.
$IBLDR  PLOTI
$IBLDR  PLT1.
$IBLDR  RDIN
$IBLDR  .SKPFL
$IBLDR  UNLOA.
$IBLDR  UN12
$ORIGIN         A
$IBLDR  INITL.
$IBLDR  INPUT.
$IBLDR  CREAD.
$IBLDR  IDENT.
$IBLDR  NUMB.
$IBLDR  REALF.
$IBLDR  SCARD.
$IBLDR  SYMBL.
$ORIGIN         C
$IBLDR  RESET.
$IBLDR  RESTA.
$ORIGIN         C
$IBLDR  ARSIM.
$IBLDR  CALBR.
$IBLDR  CGDEL.
$IBLDR  CHINP.
$IBLDR  COM.
$IBLDR  CONST.
$IBLDR  DIFDE.
$IBLDR  DIM.
$IBLDR  GENID.
$IBLDR  GRAPH.
$IBLDR  IDC.
$IBLDR  IFILE.
$IBLDR  KEEP.
$IBLDR  LAB.
$IBLDR  LIMIT.
```

```
$IBLDR  PLTO.
$IBLDR  POLIS.
$IBLDR  REWD.
$IBLDR  SAVE.
$IBLDR  SCAN.
$IBLDR  SKPF.
$IBLDR  STDPL.
$IBLDR  STDPR.
$IBLDR  TAPUC.
$IBLDR  TITLE.
$IBLDR  UPDT.
$IBLDR  UPEXP.
$IBLDR  VAR.
$IBLDR  WPACK.
$ORIGIN        A
$IBLDR  REDUC.
$IBLDR  TABRE.
$ORIGIN        A
$IBLDR  PGET.
$IBLDR  SKIP.
$IBLDR  STORE.
$IBLDR  UNPK.
$ORIGIN        B
$IBLDR  AVERA.
$IBLDR  CARD.
$IBLDR  CHDAT.
$IBLDR  COMCA.
$IBLDR  FTAPE.
$IBLDR  INDX.
$IBLDR  LINEQK
$IBLDR  METR.
$IBLDR  REJEC.
$IBLDR  REREA.
$IBLDR  SWITC.
$IBLDR  TAPEI.
$IBLDR  VPOIN.
$ORIGIN        B
$IBLDR  CREAT.
$IBLDR  GPLOT.
$IBLDR  INITP.
$IBLDR  PLTST.
$IBLDR  PREPL.
$IBLDR  PREP1.
$IBLDR  PUPDT.
$IBLDR  SCLE.
$IBLDR  SPPLT.
$IBLDR  STRPL.
$IBLDR  XYMIN.
```

```
$ORIGIN        B
$IBLDR  MATCH.
$IBLDR  VARST.
$IBLDR  F0A
$IBLDR  F1A
$IBLDR  F2A
$IBLDR  F3A
$IBLDR  F4A
$IBLDR  F5A
$IBLDR  F6A
$IBLDR  F7A
$IBLDR  F8A
$IBLDR  F9A
$ORIGIN        B
$IBLDR  FIRST.
$IBLDR  INTG.
$IBLDR  MAXMI.
$IBLDR  OCTAB.
$IBLDR  OTABL.
$IBLDR  SCANO.
$IBLDR  STAT.
$IBLDR  TAB1.
$IBLDR  WRT.
$IBLDR  WRT1.
$ORIGIN        A
$IBLDR  CRVSC.
$IBLDR  DRAWP.
$IBLDR  PCURV.
```

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